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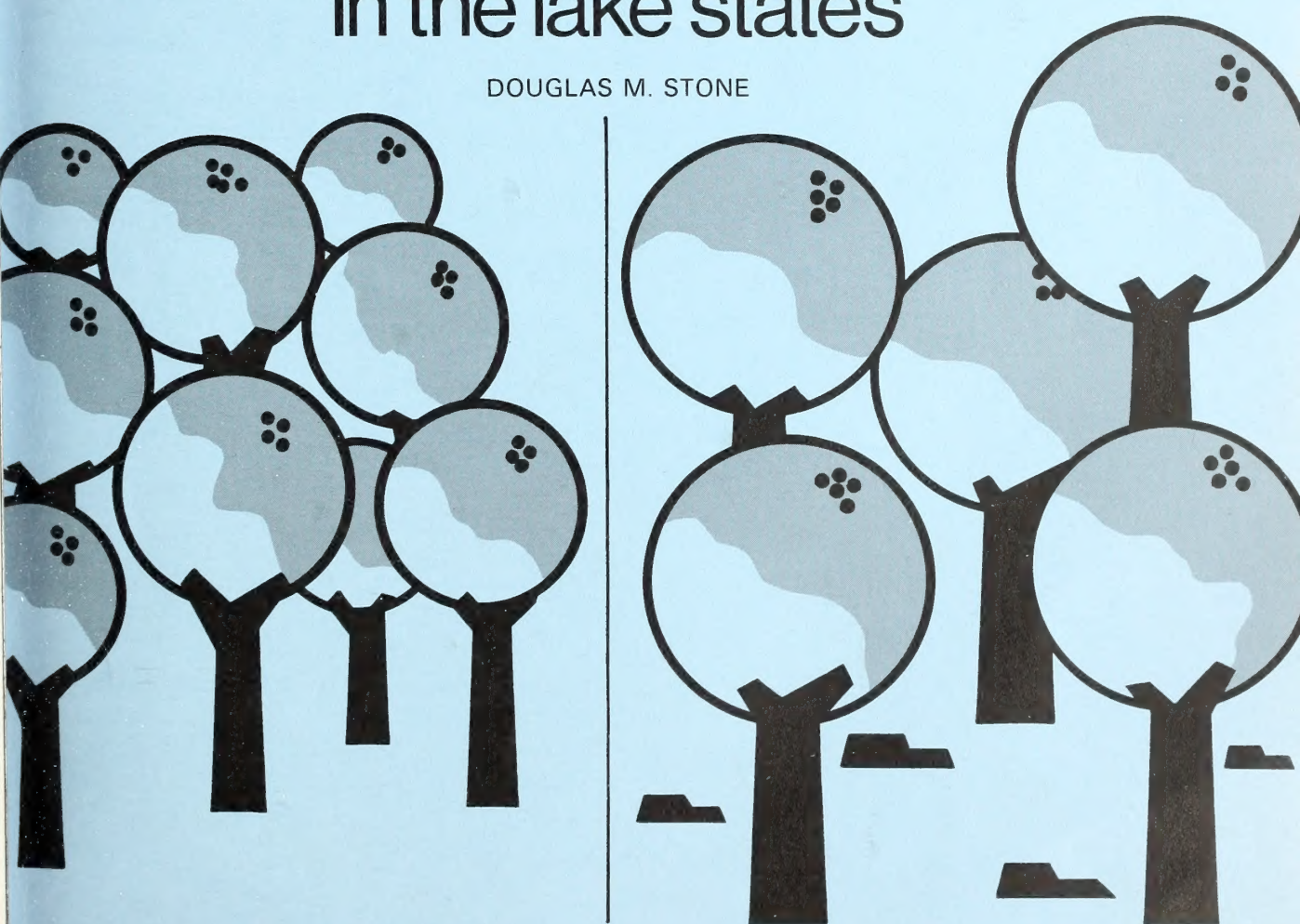
FERTILIZING and THINNING NORTHERN HARDWOODS
In the lake states

DOUGLAS M. STONE



ORTH CENTRAL FOREST EXPERIMENT STATION
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.S. DEPARTMENT OF AGRICULTURE

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FERTILIZING AND THINNING NORTHERN HARDWOODS IN THE LAKE STATES

Douglas M. Stone

The northern hardwood forest type oc-
es 32 million acres (13 million ha) in
ıortheastern United States and more than
illion acres (28.4 million ha) in Canada
gley and Babcock 1969). In the Lake
es, northern hardwoods occupy about 10
lon acres (4 million ha), comprised
ominantly of second growth stands. They
lominated by such high value species as
: maple and yellow birch, which have
potential for intensive management.
stumpage prices for quality hardwoods
shortages of the better grades of saw
and veneer have stimulated interest in
intensive management. So we initiated
.es to explore cultural practices de-
:d to increase growth rates and hasten
›roduction of veneer and saw logs from
id growth northern hardwood stands.

METHODS

Four studies were established in six
/ stocked northern hardwood stands in
/pper Peninsula of Michigan and north-
ern Wisconsin. All six stands developed
: heavy cutting 50 to 60 years ago and
›redominantly even-age with a scattering
ırger residual stems. Five of the
ls are growing on medium to good sites
: indexes 60 to 70 (18.3 to 21.3 m))
:ontain many potential crop trees. In
: stands we selected and fertilized in-
lual trees. The sixth stand is on a
:ively poor site (site index 54 (16.5
ınd includes very few potential crop
:. On this site, 0.1-acre plots were
.lized and all trees 3.0 inches (7.6
l.b.h. and larger were measured. Re-
: for each site were evaluated by anal-
of variance.

All of the stands were fertilized in
›pring before leaf-out; each stand was
:ed only once. In the five stands using
|idual crop trees, fertilizers were
surface broadcast on a 0.01 acre (0.004 ha)
plot surrounding each study tree. In the
other stand (near Hurley, Wisconsin), fer-
tilizers were broadcast on 0.1 acre (0.04
ha) plots and on 19-foot (5.8 m) isolation
strips around each plot. The location and important characteristics of each study follows:

Well-Drained Sites

Sugar Maple

A combined thinning and fertilization study was installed in two pole-size sugar maple (*Acer saccharum* Marsh.) stands, each with an abundance of potential crop trees. One stand (Dukes) is located on the Upper Peninsula Experimental Forest near Marquette, Michigan. The soil is a well-drained sandy loam; site index for maple is about 65 (19.8 m). The other stand (Melstrand) is on the Grand Sable State Forest near Munising, Michigan. The soil is a well-drained loamy sand with finer-textured bands in the subsoil; site index is 62 feet (18.9 m). More detailed stand and site conditions have been reported (Stone and Christenson 1974).

Half the study trees were released by cutting all competing trees with crowns within 5 to 10 feet (1.5 to 3.0 m) of the crop tree crowns. One of the following treatments was then applied to six thinned and six nonthinned trees:

(1) Control--no treatment.
(2) N--100 lb/acre (112 kg/ha) elemental nitrogen.
(3) NP--N plus phosphorus at 100 lb/acre (112 kg/ha) P_2O_5.
(4) NK--N plus potassium at 100 lb/acre (112 kg/ha) K_2O.
(5) NPK--N plus P plus K as above.
(6) 3N+PK--N at 300 lb/acre (336 kg/ha) plus P and K as above.

The nutrient sources were ammonium nitrate, treble superphosphate, and muriate of potash. The treatments were replicated 6 times on each site for a total of 144 study trees. Diameters were measured to the nearest 0.01 inch (0.25 mm) at breast height each fall. Results were evaluated by analysis of variance to separate the effects of thinning from those of fertilization.

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Yellow Birch

This study was installed to determine if growth of previously released pole-size yellow birch (*Betula alleghaniensis* Britton) could be increased by fertilization and to see if soil drainage would affect the response to fertilization.

One stand (AuTrain) is growing on the Hiawatha National Forest near Munising, Michigan. The soil is a well-drained complex of loamy, fine sands; site index for birch is about 65 (19.8 m). The stand is predominantly pole-size birch and maple with an occasional hemlock (*Tsuga canadensis* (L.) Carr.); it had been commercially thinned 8 years before treatment.

Moderately Well-Drained Sites

Yellow Birch

This stand is on the Ottawa National Forest near Kenton, Michigan. It is primarily a hemlock-hardwood stand with a scattering of red maple (*Acer rubrum* L.). This is a moderately well-drained site with a heavier (silt loam) soil texture; site index is 70 (21.3 m) for birch. This stand was commercially thinned 4 years before treatment. Both stands were fertilized in mid-May, 1972, using the same procedures and application rates used in the previous study. The 6 treatments are replicated 9 times on each site for a total of 108 study trees.

Sugar Maple

This study was installed to see if the more favorable competitive status of previously released sugar maple crop trees would enable them to more effectively utilize the added nutrients. In addition, we wanted to compare the results of our individual crop tree release with a commercial thinning, and to evaluate ammonium nitrate and urea as nitrogen sources.

The stand is on the Munising District, Hiawatha National Forest, near Chatham, Michigan. It is predominantly maple with a few yellow birch, and an occasional beech (*Fagus grandifolia* Ehrh.). Half of the stand had been commercially thinned 5 years before, and the other half had been marked for a thinning to be made a couple years after fertilization. The soil is similar to that at Dukes, but has a slightly heavier texture, very fine sandy loam, particularly in the upper horizons where root density is greatest. Internal drainage is more restricted than at Dukes due to a dense fragipan at about 16 inches (40 cm). It is classed as moderately well drained. Site index for maple is a little more than 60 feet (18.3 m).

Groups of six trees, well matched for crown size and initial d.b.h., were selected in both the thinned and nonthinned parts of the stand. In early May, 1972, one of the following treatments was applied to each tree in each group.

(1) Control--no treatment.
(2) AN--N at 100 kg/ha (89 lb/acre) as ammonium nitrate.
(3) AN+PK--N as above plus P and K each at 50 kg/ha (44.5 lb/acre).
(4) UN--N at 100 kg/ha (89 lb/acre) as urea.
(5) UN+PK--N as above plus P and K each at 50 kg/ha (44.5 lb/acre).
(6) 3UN--N at 300 kg/ha (267 lb/acre) as urea.

Treble superphosphate and muriate of potash were the other nutrient sources. Treatments were replicated 10 times in each portion of the stand for a total of 120 sample trees.

Sugar and Red Maple

This study was established in 1966 near Hurley, Wisconsin. Species composition was variable but averaged 72 percent sugar maple and 18 percent red maple; miscellaneous hardwood species made up the other 10 percent. The soils on these plots are a heterogeneous mixture; about two-thirds of the area is moderately well drained, and one-third is somewhat poorly drained. Soil texture ranges from sandy loam to silt loam with very fine sandy loam predominant. Site index for sugar maple and red maple averages 54 feet (16.5 m), somewhat below average for the area (Carmean and Watt 1975). Tree quality is distinctly below average due to generally poor form and a high incidence of stem defects throughout most of the stand.

Eighteen 0.1-acre (0.04 ha) plots were laid out and all trees 3.0 inch (7.6 cm) d.b.h. and larger were measured and marked.

Due to wide variation in stand and site conditions two plots were rejected initially and a third was deleted later. This left three replications of the following five treatments:

(1) Control--no treatment.
(2) N--N at 150 lb/acre (168 kg/ha).
(3) P--phosphorus at 150 lb/acre (168 kg/ha).
(4) NP--N and P each at 150 lb/acre (168 kg/ha).
(5) NPK--N, P, and K each at 150 lb/acre (168 kg/ha).

The nutrient sources were ammonium nitrate, treble superphosphate, and muriate of potash; all application rates were on an elemental basis.

RESULTS

Well-Drained Sites

Sugar Maple

After three growing seasons there has been no significant difference in d.b.h. growth due to fertilization. In fact, most of the fertilized trees have grown less than the controls (table 1). This occurred with both thinned and nonthinned trees on both sites. Of the nonthinned trees at Dukes, for example, d.b.h. growth in all fertilizer treatments has averaged less than that of those not fertilized. At Melstrand, nonthinned trees that received NPK grew 5 percent more than the controls, but those in all other treatments grew less. Of the released trees, two treatments averaged slightly more than the controls, but all others grew less. At Dukes, released trees fertilized with 3N+PK were the same as the controls, those that received NP grew 2 percent more, and all others grew less.

Thinning was far more effective than fertilization in stimulating diameter growth. There was a statistically significant increase due to thinning on both sites every year. For the 3-year period, the thinning response of nonfertilized trees was about 80 percent on the sandy loam at Dukes and 72 percent on the sand at Melstrand. Fertilized trees also responded well to release. Although actual growth averaged somewhat less than that of nonfertilized trees, the response to release was slightly greater, 82 percent at Melstrand and 90 percent at Dukes.

Yellow Birch

The birch poles on the well-drained sand at AuTrain have shown no significant response to fertilization. Trees in the NP treatment grew 14 percent more than the controls, and those that received the triple N combination averaged 9 percent more, but those in the other three treatments all have grown less (table 2).

Moderately Well-Drained Sites

Yellow Birch

Fertilized trees growing on the moderately well-drained silt loam at Kenton

Table 1.--*Mean annual d.b.h. growth of maple poles on two sites (treatments applied in early spring 1971)*

Treatment	Nonthinned					Thinned				
	1971	1972	1973	3-year average	Response[1]	1971	1972	1973	3-year average	Response
	Inches				*Percent*	*Inches*				*Percent*
DUKES										
Control	0.140	0.125	0.158	0.141	--	0.188	0.265	0.307	0.253	--
N	.107	.102	.123	.111	-22	.163	.210	.197	.190	-25
NP	.113	.120	.117	.117	-17	.240	.245	.292	.259	2
NK	.115	.118	.110	.114	-19	.182	.223	.238	.214	-15
NPK	.127	.127	.128	.127	-10	.165	.228	.263	.219	-14
3N+PK	.123	.130	.133	.129	-9	.188	.262	.310	.253	0
MELSTRAND										
Control	0.110	0.105	0.147	0.121	--	0.173	0.187	0.263	0.208	--
N	.080	.092	.108	.093	-23	.133	.193	.252	.193	-7
NP	.110	.105	.120	.112	-7	.153	.212	.297	.221	6
NK	.117	.103	.122	.114	-6	.185	.210	.308	.234	13
NPK	.112	.115	.153	.127	5	.157	.160	.237	.184	-11
3N+PK	.090	.112	.135	.112	-7	.123	.173	.247	.181	-13

[1]To minimize errors due to rounding the figures in this column (all tables) are based on total cumulative growth rather than the 3-year average.

Table 2.--*Mean annual d.b.h. growth of previously released yellow birch poles on two sites (fertilizers applied in May 1972*

Treatment	1972	1973	1974	3-year average	Response
	Inches				*Percent*
AUTRAIN					
Control	0.212	0.240	0.219	0.224	--
N	.216	.234	.196	.215	-4
NP	.239	.273	.252	.255	14
NK	.239	.221	.187	.216	-4
NPK	.199	.210	.176	.195	-13
3N+PK	.244	.268	.220	.244	9
KENTON					
Control	0.152	0.184	0.161	0.166	--
N	.199	.247	.213	.220	32
NP	.197	.210	.177	.194	17
NK	.183	.236	.192	.204	23
NPK	.181	.226	.186	.197	19
3N+PK	.167	.231	.173	.190	14

have tended to respond to fertilization. Although the results are not significant statistically, several trends are evident:

(1) 100 lb/acre (112 kg/ha) of N as ammonium nitrate was the most effective treatment. The addition of P and/or K decreased the response to N (table 2).

(2) The most expensive 3N+PK combination gave the least response. By the third year, growth was only slightly greater than the controls; that of trees that received N alone was still about 30 percent greater. The 32 percent response to N alone has resulted in growth about equal to that of the nonfertilized trees on the well-drained site at AuTrain.

Sugar Maple

Fertilization has not significantly changed the growth rate of either the thinned or nonthinned maples on the South Superior site. However, like the yellow birch on the moderately well-drained site at Kenton, fertilization has produced some slight trends (table 3). Nitrogen at 100 kg/ha (89 lb/acre) applied as ammonium nitrate increased d.b.h. growth of nonthinned trees by 11 percent and that of thinned trees by 14 percent. However, the addition of P and K decreased the N response of the thinned trees and nullified it in the nonthinned trees. The same amount of N applied as urea showed little response by either thinned or nonthinned poles. Urea plus P and K gave a 13 percent increase in the nonthinned part of the stand, but nothing in the thinned portion. The triple rate of N (300 kg/ha) as urea produced a slight increase over the lower

Table 3.--*Mean annual d.b.h. growth*[1] *of fertilized sugar maple poles on a moderately well-drained site (South Superior)*

Treatment	1972	1973	1974	3-year average	Response
	Inches				*Percent*
NONTHINNED					
Control	0.106	0.134	0.095	0.112	--
AN	.118	.150	.102	.123	11
AN+PK	.114	.142	.075	.110	-1
UN	.118	.134	.087	.113	1
UN+PK	.126	.134	.118	.126	13
3 UN	.110	.154	.098	.121	8
PREVIOUSLY THINNED					
Control	0.138	0.193	0.138	0.156	--
AN	.189	.201	.146	.178	14
AN+PK	.154	.205	.138	.165	6
UN	.158	.189	.142	.163	4
UN+PK	.162	.189	.114	.155	-1
3 UN	.150	.209	.142	.164	7

[1]Original measurements made in metric units; converted to inches to facilitate comparison with other studies in this report.

rate, but less than that of N at 100 kg/ha applied as ammonium nitrate. The overall increase for all fertilization treatments averaged about 6 percent.

In contrast to the lack of a significant response to fertilization, there has been a highly significant increase in growth following thinning. The thinning responses varied from 23 percent in the UN+PK treatment to 51 percent in the AN+PK treatment; the average was about 40 percent for all treatments combined. The growth response following commercial thinning on this site was substantially less than that observed in the individual crop tree release at Dukes (table 1). Nevertheless, the nonfertilized trees in the thinned portion of the stand have grown nearly 25 percent more than the best fertilizer treatment in the nonthinned part of the stand, and 32 percent more than the average for all fertilized but nonthinned trees (table 3).

Sugar and Red Maple

Growth has been extremely poor on the site at Hurley, and there has been no significant increase due to fertilization. On a percentage basis, growth on the N and NP plots appears much greater than that on the control plots, but the actual differences are small (table 4). If growth continues at these same rates, for example, it will take nearly 30 years for the poles on the N plots to gain an inch (2.54 cm) in d.b.h. over those on the control plots. Phosphorus fertilizer was of no apparent

Table 4.--*Eight-year d.b.h. growth of sugar and red maple poles (4.6 to 8.5 in.) fertilized in May, 1966, Hurley, Wisconsin*

Treatment	Block			Plot average	Mean annual	Response
	I	II	III			
	Inches					*Percent*
Control	0.56	0.60	0.55	0.57	0.072	--
N	.75	.90	.97	.86	.107	49
P	.59	.43	.68	.53	.066	-8
NP	.78	1.09	.56	.75	.093	29
NPK	.87	.68	.58	.69	.086	19

benefit on this site; after 8 years, growth has averaged 8 percent less than on the control plots. The complete NPK treatment was less effective than the NP combination and substantially less than N alone.

The smaller size classes, i.e., 3.0 to 4.5 in. (7.6 to 11.4 cm) d.b.h. have grown less than the poles (Carmean and Watt 1975). Including these trees in the analysis gives a mean annual growth of 0.053 in. (0.135 cm) for the control trees, and 0.071 in. (0.180 cm) on the nitrogen plots. Although this represents a 34 percent response at these growth rates, it would require about 56 years for the fertilized trees to average 1.0 in. (2.54 cm) more than the controls.

No thinning treatments were included in this study. This is unfortunate because diameter growth of maple poles is strongly influenced by stand density. In fact, well over half of the variation in 8-year diameter growth of maples on these plots is explained by the variation in initial stand density. The "response" to N and NP for example, occurred on plots averaging 78 and 82 ft^2 of basal area per acre (17.9 and 18.8 m^2/ha) while the control and P plots averaged 94 and and 100 ft^2 (21.6 and 23.0 m^2/ha). This alone accounts for much of the variation in the growth rates indicated in table 4.

DISCUSSION

None of the fertilization treatments on these six sites has shown a statistically significant increase in d.b.h. growth over the first 3 years following fertilizer application. In general, released trees on the well-drained sites (Dukes, Melstrand, and AuTrain) have grown at greater than 0.2 in. (0.51 cm) per year and fertilization has tended to decrease these rates, at least at breast height (tables 1 and 2). Corresponding trees on the more moist (moderately well-drained) sites (Kenton and South Superior) have grown at less than 0.2 in. (0.51 cm) per year and have tended to respond to fertilization (tables 2 and 3). However, the initial trends are relatively small and unless they increase substantially, will require several years to gain an inch (2.54 cm) in diameter over the nonfertilized controls (table 5), particularly the slow-growing stand at Hurley (table 4).

In contrast to the small and variable fertilization responses, those due to thinning have been large and consistent. Moreover, they are statistically significant on both well-drained and moderately well-drained sites. The thinning responses range from 39 percent in the commercially thinned stand on the South Superior site to 80 percent from the individual crop tree release at Dukes (table 5). This amounts to a little over 6 rings per inch (2.54 cm) at South Superior, and about 4 per inch at Dukes--growth rates that are substantially greater than any of the fertilizer treatments have produced without thinning.

Although these results are not final, they do have management implications. Pole-size birch and maple growing on well-drained soils of medium and better site quality respond well to release, both on an individual crop tree basis and by commercial thinning. The maple poles in these studies have grown at 4 to 5 rings per inch following crop tree release; previously thinned (commercially) yellow birch poles have averaged 4.5 rings per inch. Adding fertilizers to these sites has resulted in decreased d.b.h. growth more often than it has increased it. Thus, competition for other factors appears to limit growth more than availability of mineral nutrients on well-drained soils with a site index of 60 and greater. In condsidering silvicultural investments on these sites, these data indicate that regulation of stand density should have first priority.

Table 5.--*Soil characteristics, most responsive treatments, mean annual increment, and growth responses of young northern hardwoods on six sites in Upper Michigan and northern Wisconsin*

Study area	Species	Site index	Soil texture	Drainage classification	Treatments	M.A.I.	Growth response	
						(in.)	*Percent*	yr/in.
Dukes	SM[1]	65	SL[2]	WD[3]	Thinning	0.253	80[4]	9
					Thin+NP	.259	84[4]	8
Melstrand	SM	62	LS	WD	Thinning	.208	72[4]	11
					Thin+NK	.234	93[4]	9
AuTrain	YB	65	LS	WD	NP	.255[5]	14	32
Kenton	YB	70	SiL	MW	N	.220[5]	32	19
South Superior	SM	60	SL	MW	NPK	.126[6]	13	71
					N	.178[7]	14	45
					Thinning	.156[8]	39	23
Hurley	SM,RM	54	VFSL[9]	MW[9]	N	.071[10]	34	56
						.107[11]	49	29

[1]SM= sugar maple, YB= yellow birch, RM= red maple.
[2]SL= sandy loam, LS= loamy sand, SiL= silt loam, VFSL= very fine sandy loam.
[3]WD= Well-drained, MW= moderately well-drained.
[4]Compared to nonthinned and nonfertilized trees.
[5]Commercially thinned stands.
[6]Nonthinned portion of the stand.
[7]Previously thinned portion of the stand.
[8]Nonfertilized trees in thinned vs. nonthinned portion of the stand.
[9]Variable; the predominant condition on the site.
[10]All trees 3.0 in. d.b.h. and greater.
[11]Poles 4.6 to 8.5 in. d.b.h.

The fertilization trends observed on the more moist (moderately well-drained) soils are promising but have not been consistent enough to significantly increase growth of fertilized trees over the nonfertilized ones on those sites. Because of the differences in species, stocking, and site quality, exact comparisons cannot be made between stands. In general, however, diameter growth on the moderately well-drained soils was better related to site quality than to added nutrients. In these three stands, site indices ranged from 70 (21.3 m) at Kenton, to about 60 (18.3 m) at South Superior, down to 54 (16.5 m) at Hurley; mean annual d.b.h. growth of nonfertilized trees was in the same order: 0.17 (0.42 cm) at Kenton, 0.11 (0.28 cm) on the South Superior, and 0.07 (0.18 cm) at Hurley. Returns on investments in timber management can be expected to follow the same order. Considering the most responsive treatment on each site, for example (table 5), the poles at Kenton have averaged 4.5 rings per inch, those on the South Superior about 5.5, and those at Hurley 9.5 rings per inch.

On a percentage basis, this order is reversed: i.e., the least response occurs on the best site, and the greatest on the poor site. This anomaly occurs frequently when comparisons are made between studies where initial conditions are not comparable. Because growth tends to be relatively low on poor sites, a small actual response may appear large when expressed as a percent of the control. As reiterated by Leonard *et al.* (1972), a 100 percent increase of near-nothing is still near-nothing. A more realistic comparison is given by either (1) the mean annual increment, or (2) the time required for the response to gain an inch (2.54 cm) in d.b.h. over the controls at the measured growth rate (table 5). For example, thinning on the South Superior site and fertilization at Hurley each produced a similar response on a percentage basis (table 5). The actual response, however, was much greater at South Superior, where thinned trees will average an inch more than nonthinned trees in 23 years. In contrast, the 34 percent response at Hurley would require 56 years for the fertilized trees to average an inch more than the controls, if it would last that long.

Expressing growth responses as years per inch rather than as percentage also illustrates the relation between the magnitude of fertilizer responses and site quality. At these growth rates, the poles in the most responsive treatments on the moderately well-drained sites will average an inch more than the corresponding control trees in 19 years on the best site at Kenton, in 23 years on the medium site at South Superior, and in 29 years on the poor site at Hurley.

CONCLUSIONS

Fertilizing birch and maple poles on well-drained soils with site indices of 60 (18.3 m) and over generally decreased d.b.h. growth the first 3 years. On three moderately well-drained soils, fertilization has stimulated growth slightly, but the increases were relatively small and were not statistically significant. On these more moist sites the magnitude of the fertilization response was related to site quality as reflected by the site index. The largest actual growth response occurred on the best site and the smallest on the poor site; on a percentage basis this order was reversed.

Thinning significantly increased growth each year on all sites where it has been evaluated. The growth responses following thinning have been much larger and far more consistent than those due to fertilization.

These results indicate that: (1) on well-drained soils with site indices of 60 (18.3 m) and greater, diameter growth of pole-size birch and maple growing in even-age stands is limited more by competition than by availability of N, P, or K. In considering silvicultural investments on these sites, regulation of stand density should have first priority. (2) The chances of stimulating growth by fertilization are greatest on moist (moderately well-drained) sites where available soil water is sufficient and apparently enables the crop trees to utilize the additional nutrients more effectively. The size of the growth responses is related to stand conditions and site quality as indicated by the site index. The most promising trends have occurred on the better sites.

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A GUIDE TO THE APPRAISAL OF WILDFIRE DAMAGES, BENEFITS, AND RESOURCE VALUES PROTECTED

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INTRODUCTION

The purpose of this paper is to present concepts and methods for appraising damages and benefits resulting from wildfire and wildland resource values protected that will be more useful than present appraisal methods for making fire prevention, presuppression, and suppression decisions. The same concepts and methods may serve the needs for appraising damage for trespass claims as well as for planning.

Wildland fire control is an expensive necessity to conserve natural resources and property and to ensure public safety. More than $100 million, mainly tax revenues, is spent annually on wildland fire control in the United States. Although progress has been made in fire prevention, there is an irreducible risk of wildland fires starting, spreading, and doing damage so that fire control efforts will be needed indefinitely.

Rising costs of fire control coupled with increasing values of resources in recent years has caused much concern among the Congress, State legislatures, fire control administrators, and the public about the allocation of funds for fire control. Although adequate fire control is difficult to define, it must satisfy the needs for controlling fire and it must be carried out efficiently within limited budgets.

Guiding policy has been couched in general terms. For example, a goal of the USDA Forest Service is to provide "control of fires commensurate with values protected". Another often-used but more specific objective is to provide protection at the "least-cost-plus-loss". Both objectives require sound damage and value protected information in order to measure achievement.

Theoretically, an economic analysis should provide sound guides to both adequate and efficient fire control, but in practice there have been many difficulties. One serious problem is that the quality of information on fire damages, benefits, values protected from fire, and even resource values has been very poor. As a result it has been nearly impossible to satisfactorily analyze fire control needs and accomplishments on an economic basis. Such an analysis would be invaluable to guide decisions in planning, budgeting, and in actual fire suppression.

Costs can be obtained accurately by bookkeeping. Most appraisals of wildland fire damage have been based largely on property, timber, and range resource losses that lend themselves reasonably well to accepted valuation techniques. But appraisal of losses is inadequate for the more subjectively valued resources such as watersheds, recreation, wildlife, and the environment. The increasing importance of these later resources in todays society makes it necessary to appraise them more realistically.

The biological, economic, and psychological impacts of forest fires are complex. Imperfect biological prediction and economic models hamper sound appraisal. Owing to traditional and sometimes illogical concepts, the lack of definitive valuation methods, and to the diversity of opinion on these items, it appeared at the outset of this study that attention was needed to develop logical valuation concepts as well as to formulate some methods for their application. Unless agreement can be reached on concepts and method, appraisal will continue to frustrate resource managers.

A major thesis presented here is that appraisals are needed as tools for fire control planning and management. All too often "damage" has been treated as a statistical item required to complete a fire report. The objective of providing a tool for the decisionmaker as planner, administrator, or as fire suppression officer, however, sets the purpose of appraisal in a different context and should give new direction to the appraisal process.

Because fire control decisions are made throughout the line of authority

from policy making to suppression of active fires, it is essential that the same concepts and methods be recognized and understood by all the people making these decisions.

HOW VALUES-AT-RISK RELATE TO RESOURCE APPRAISAL

Forests and other wildlands contain widely different combinations of vegetation, soils, animals, climate, configuration, and ecological interactions. Any part or all of a particular combination may satisfy human needs. Values-at-risk indicate any or all of the useful resources jeopardized when a fire occurs.

Forest and other wildlands are valuable because they serve human needs. Value is thus a cultural characteristic of wildland resources rather than an intrinsic property. Regardless of the functions served by wildlands, value derives from the supply of products and services and the demand for them.

Value for our purposes thus evolves from the use of and plans for use of the wildland products and services. Moreover values will change when objectives of use change. It follows that forest and wildland fire control is carried on to permit the achievement of certain social and economic resource-related goals. Fire control is successful if it keeps fire from preventing goal achievement and unsuccessful if goal achievement is hindered or prevented.

Damage or benefits occur only if the achievement of goals is altered unfavorably or favorably, respectively, by fire-caused physical changes. Moreover, because the physical fire effects must be evaluated in terms of goal achievement, the socioeconomic effects of fires uniquely determine the significant physical changes that must be identified and measured for damage appraisal.

"Value protected" is conceived here to include only the partial resource value subject to fire damage. This is a meaningful value representation for fire-control planning and decisionmaking because it is possible for certain resources to be relatively immune to fire damages and, in some cases, some fires may produce benefits.

Neither appraised damage from a given fire nor value protected may be greater than the prefire resource value. Benefits, however, may accrue to prefire resource values. The following statements about these relations can be made if it is assumed the area appraised is some given unit of resource management and losses are based on a given size and intensity of fire:

(1) Resource value $\geq$ value protected = maximum potential damage $\geq$ appraised damage.

(2) Fire benefits = appraised values added = postfire resource value *less* prefire resource value (when result is +).

Obviously *value protected* is limited by the *value of the resource*. However, *value protected* may be much *less* than *resource value* depending upon the susceptibility of the resource to physical fire-caused changes that affect goal achievement. Moreover, the *damage* caused by a given fire may vary from 0 to 100 percent of *value protected*. The *damage* as a portion of *value protected* varies with the severity of the fire, the susceptibility of the resource to destruction, and, in some instances, to the area burned.

DEFINITIONS

Damage: The unfavorable effect of fire-caused changes in the resource base on the attainment of organization goals.

Benefits: The favorable effect of fire-caused changes in the resource base on the attainment of organization goals.

Value protected: The maximum potential resource value that can be destroyed by fire on a resource management unit. This would reflect the maximum potential fire-caused reduction in goal attainment.

Resource value: The full value of the resource, including maximum damagable value (value protected) and remaining nondamagable value.

Because damage and value protected are goal oriented, it is essential to know and understand the goals of the wildland managing organizations for which appraisals are being made. For example, achievement of 4 of the 11 goals found in the USDA Forest Service "Framework for the Future" are affected by forest fires. These goals can be translated into general objectives as follows:

1. To ensure that forest fires do not significantly interrupt or reduce the continued supply of products or services and productive capacity of wildland resources needed for the physical and economic needs of society.

2. To prevent destruction of real and personal property and improvements by forest fires.

3. To ensure minimum fire-risks to the safety, health, and survival of the people in and near the forest and wildlands.

4. To protect, maintain, and/or improve the quality of the environment.

These objectives imply that values-at-risk are diverse. They involve measurable products or services, each supported or created from different sets of wildland components and/or attributes (table 1).

Values-at-risk can be categorized as (1) forest or wildland resource values--values derived from forest resources and forest resource products; (2) nonforest resource values--values independent of forest values but influenced by fires; and (3) environmental values-at-risk--values related to the environment that overlap both of the foregoing.

The *resource* group includes timber, range, watershed, recreation, and wildlife resources. The *nonforest group* includes values such as human life, health, physical and economic well-being, real and personal property, and conservation of "energy".

Damage to nonforest values is directly caused by the flames, heat, and/or smoke per se; there are few after effects. Most benefits of fire control to the nonforest group accrue from total fire prevention. In these instances the wildland provides a fuel hazard threatening nonforest values,

Table 1.--*Kind of resource value protected, composition, product and product use, and measure appropriate for fire-damage appraisal purposes*

Values-at-risk	Resource composition	Resource product	Physical or biological measure
FOREST RESOURCES			
Timber supply	Merchantable or potentially merchantable trees and soil productivity.	Wood and related products.	Wood volume--present or future.
Range	Grasses, herbs, browse plants, and soil productivity.	Forage	Tons/acre - AMU.
Watershed service	Live and dead organic soil cover, growing conditions, soil characteristics, topography, and stream channels regulating water storage and runoff and soil erosion.	Service: water processing and storage, stream flow regulation, and soil stabilization.	Change in watershed behavior and associated economic and social effects.
Recreation opportunity	Any wildland feature, substance, or situation providing an opportunity for recreation activities (uniquely determined by the activity).	Human satisfaction from experiencing recreation activities. Product is also a user- or visitor-day.	No direct measure. Indirect measure--change in use of site, i.e., visitor days.
Wildlife and wildlife habitat	Wildlife populations and habitat.	Food, fur, recreation, and environmental enjoyment, satisfaction or service.	Pounds, number, quality, recreation-day, relative quality of environment as affected by changes in animal populations.
NONFOREST RESOURCES			
Public safety	People protected.	Personal health (physical and mental well being).	Injuries, sickness, and deaths and/or economic consequences.
Property	Real and personal property, improvements. Commercial facilities.	Services (shelter, manufactured products, comforts, safety, conveniences, etc.).	Property description and significance.
ENVIRONMENTAL VALUES			
Life functions and visual and sensory preception.	Vegetation, soil, water, air, surface configuration, animals, and certain interrelations as climate, ecological states.	Environmental quality within acceptable limits in support of plant and animal life processes; and sensory preceptions.	Measures of: land, air water, and other preceptive quality (parts/million, etc.) and personal responses to change in quality.

whereas in the forest resource group, the forest itself is a resource value-at-risk and many complex after effects may result.

Environmental values are a mixture of the two former types and are categorized separately. Certain local environmental conditions may be created or strongly influenced by wildland, such as air and water quality or scenic quality. While the wildland is burning, environmental changes occur "downstream" (smoke effects) although other onsite effects may persist (ugliness). Whether transient or persisting, such effects may evoke strong responses from residents and often from nonresidents.

Subjective, environmental values can outrank the forest resource values in priority for protection. Thus, they must be accounted for in some value scale.

These distinctions have more than academic importance if for no other reason than they direct the purpose, priority, and technology of fire-control planning and execution. Organizations oriented towards *resource* protection *only* may be unprepared, underfinanced, or even unauthorized for the different methods and demands imposed on them by the extension of protection to the nonforest and environmental values. For example, a high level of fire control might be required by the public for the safety of people living in a flammable semiwildland setting regardless of the *forest resource* values protected. Or, the current interest in "environmental quality" may force fire-control organizations to protect *environmental values* per se, irrespective of any *forest or nonforest resource values.*

VALUATION METHODS

One approach to estimating effects of fire-caused changes on the attainment of objectives is the measurement of the reduction of National, State, or regional income caused by wildfires. Estimates should be made using the most appropriate method, which Streeby listed as follows: market price, conversion return, discounted net value, discounted conversion return, replacement costs, and user cost. A narrative statement of the significance of physical fire-caused changes should be used as a last resort. "Relative value", which is useful to designate differences among levels of value of the same resource has use in some planning techniques.

Values-at-risk protected from fire vary in the nature and marketability of their products. Some, such as wood products, enter well-developed markets in which prices are established. Others, such as recreation products, environmental values, and wilderness, are subjective in nature (nonmarket) and do not enter formal markets where prices for products or services are established. Nevertheless, these products are subject to forces of supply and demand that determine their value. Because of the variability in nature of products, and markets, all of the methods are useful in making wildland appraisals.

If the measure of damage is to be "reduction in income", it is necessary to specify for a given appraisal and resource the level of income being considered--National, State, regional, community, or individual. However, discretion is needed. For example, a fire that destroys the local income from a recreation attraction may not be a loss to the regional income if other attractions are available nearby. Thus, the recreationist can simply transfer his spending to another location within the same region.

Dollars make the ideal common denominator for comparing and combining individual resource values. However, dollars are not necessarily a more valid value judgment than any other value statement about a resource, especially when no firm market exists. A scenic area cannot be adequately assigned a market value because scenery is not a product traded in market. However, scenery does have value, and estimates of its dollar value can be made even though not definitive. Moreover, we can analyze many of the value criterion involved to make comparative statements about scenic values in relation to other areas. Thus strict adherence to dollars is not a necessity to obtain values for planning purposes, even though dollars are needed for a strict financial analysis.

The Resource Appraisal Unit

Few, if any, wildland values are independent of the land area on which they occur. Except for very high-value individual trees, such as a large, high-quality walnut tree, most trees are merchantable as timber only when they occur in numbers sufficient to make harvesting an economic

venture. Recreation opportunities require some minimum areas for use or management. For appraising value protected an appraisal unit of management size peculiar to each resource use must be designated.

In areas managed for multiple use, the appraisal unit for each individual resource may vary in size being bounded by different kinds of limits. For example, a timber resource appraisal unit may or may not correspond with a watershed unit boundary, or a recreation unit boundary. It might be practical to appraise values protected per acre as the average of the particular unit of management for each value-at-risk, so that the sum of all values-at-risk for any one particular parcel of land can be combined to show the total resource value protected. Thus, it would be practical to let appraisal units correspond to functional management units.

Problems may arise where there is no specific plan of management for given areas, either public or private. However, all lands perform some watershed function, form a habitat, and contribute toward the environment. Therefore, some status for appraisal purposes could be assumed. Although timber, watershed, range, or recreation potential may be the best alternatives, other potential values-at-risk should not be overlooked.

Size and Intensity of Fires

High-intensity fires usually cause more and a greater degree of physical changes than do low-intensity fires. Thus, to the extent that damage is related to number and degree of physical changes, damage per acre increases with the intensity of fires. As a fire grows in size, it tends to jeopardize a broader range of objectives. Moreover size and intensity may increase simultaneously to magnify both degree and number of effects.

A fire may influence the achievement of objectives on adjacent or downstream lands. This "spilling over" effect on unburned areas increases the per acre damage on the burned areas. Suppression costs usually increase with fire size and intensity, some times drastically. The total of these costs plus damages tends to increase the value per acre protected as fires increase in size and intensity, even though the costs of suppression per acre burned tends to decrease as fire size increases.

Consequently, size and intensity of fires are important planning factors. It is especially important that some probable maximum size and intensity of potential fires be assumed when estimating the value protected.

FOREST AND WILDLAND RECREATION RESOURCE

Concept

Recreation resources are the natural features that provide an opportunity for forest and wildland recreation activities. Natural features such as openings, trees, and other vegetation, soil, rocks, water, weather, historical events, wildlife, topography, geologic formations, scenery, and other amenities provide most opportunities. The *value of recreation resources, therefore, is the value of the recreation opportunities.*

Recreation *activities* have different requirements for successful and satisfying accomplishment, so the *recreation activity uniquely defines the recreation resource for that activity.* Any appraisal of a recreation opportunity, therefore, must be made in terms of specific activities or groups of activities. The opportunity must be appraised in terms of the *required or essential features* making the activity possible and the *environmental features* that make the location for the activity an attractive place.

Environmental amenities have a stronger relation to recreation use than to any other of the multiple forest and wildland uses. Because it is necessary to relate amenities to some form of demand, they are included with recreation resources in this paper.

The *product* of the recreation resource is human satisfaction from recreation activities. This product is difficult to evaluate directly in dollars because there is no measurable unit of human satisfaction. The best expression of value of recreation opportunities is the amount people will be willing to spend to participate.

Some agencies estimate the number of recreation-days (visitor days) and assign a research-determined or arbitrary value per day to estimate recreation benefits.

Much of the recreationists dollar is spent for travel opportunities and occasions. This complicates the assessment of the value of individual public recreation opportunities. Moreover, much outdoor recreation is offered free or at nominal cost on the recreation site.

Appraisal

Recreation resource values are of two kinds: (1) the value of the resource opportunity itself; and (2) the values associated with recreation improvements. If the management objective is to provide some level and quality of recreation opportunities, and a fire destroys all or part of an opportunity, damage has occurred in the sense that goal achievement is reduced.

Because recreationists are mobile, they often find another opportunity as a substitute for the one that is lost with little or no change in their spending habits affecting National income. But if we try to maintain the same or an increasing level of opportunities in a fixed area, the part of the budget diverted to restoration, relocation, or replacement of changed opportunities may well account for part of the damage from forest fires.

From a purely monetary viewpoint, such costs may serve the need for damage appraisal. Although the urgency of demand for rehabilitation would indicate something about the demand for the opportunity, restoration costs do not tell much about the importance of the opportunity. For example, historic trees or buildings destroyed by fire could be replaced, but they would not have the same significance the originals had. The replacement cost would only be a token of some greater or smaller social loss. Some form of opportunity evaluation seems necessary. However, it is probably true that a strict financial analysis of many recreation resources falls short of a satisfactory guide to fire-control priority.

Recreation improvements represent values-at-risk--and can be considered resources. However, they are usually provided to: (1) help manage people; (2) increase the capacity for use; (3) protect the site; or (4) increase availability and use of opportunities, notable exceptions to the latter are swimming pools or impoundments. Improvements usually *enhance* the opportunity, rather than *make* the opportunity for outdoor recreation. Improvements may be costly, but they have usefulness only as long as the opportunity is viable.

If the opportunity itself is destroyed or rendered unusable for a long time (10 years), appraised damage will be the value of the lost opportunity, or the cost of its relocation, or the depreciated capital value of the improvements. *If the opportunity is still viable after a fire or its use is only temporarily reduced,* appraised damages will be the costs to restore the opportunity and the improvements if the opportunity is still needed, plus any reduction in opportunity value.

A decision on the destructability of the opportunity is critical to the appraisal. The appraiser must define the activities involved and determine the necessary resource elements for their successful accomplishment. If these elements are destroyed, the activity is no longer possible. If they are only reduced in quality, the activity may still be practiced though rehabilitation might be required.

Appraisal of the opportunity value is complex, but damages appraised, as cost of restoration, replacement, or relocation, are comparatively easy and reliable to estimate.

Fire-caused recreation benefits are possible and care must be excercised to account for them in appraisals. Improved game habitat might increase hunting success. Burned areas may provide points of interest. Fires can increase the variety of vegetation or produce new crops of berries--or openings in large areas of monotypes. Recent burns are good bird- and game-watching areas. A burn may also change the kind of activity an area may support without loss of use.

Many features that provide recreation opportunities can't be destroyed by fire. For example, lakes, beaches, geological features, mountain-climbing areas, and trails. Other features, such as groves of trees or rare plants, can be destroyed. Many activities can still be carried on after a fire, however, they may lose much of their charm because of environmental changes. Thus, the quality of environmental

features are often reduced but the essential features for the activity survive. Complications occur when a fire simply changes the activities possible but doesn't prohibit use of the area for other activities.

Evaluation of Recreational Opportunities

Private land offering recreational opportunities can often be evaluated through open-market exchanges. A reduction in value because of fire is equal to damage. This is a sound method of evaluation, but seldom is usable for public land.

A method often proposed, but seldom used for other than major recreation developments, involves preparation of a schedule of the amount of use with changing costs to participate (Clawson and Knetsch 1967). Opportunity values are actually determined by the amount people are willing to pay or forego in order to participate in activities. If these costs can be established and the number of persons who would participate at various cost levels determined, the value of the opportunity can be obtained. This information is difficult to acquire, but represents the truest expression of value because the method accounts for variation in elasticity of demand (Knetsch 1971). Clawson and Knetsch (1967) illustrated this method using travel distance as the cost variable.

Another system determines the average cost-per-day-per-person to participate in a recreation activity at a particular site. The opportunity is then valued as the product of the average cost-per-person and the number of persons participating per year, or a capitalization of the annual net costs. If realistic net-per-capita data can be found for each activity, the method is useful. Such information is not readily available and the method may severely underestimate the value for scarce high-quality opportunities (Knetsch 1971). However, a set of per-capita rates have been used in certain government estimates. For example, a useful set of per-capita rates was used in "A model for the determination of wildland resource values" (USDA Forest Service 1971a).

Because valuation of opportunities cannot be precisely made, a *relative value of recreation opportunities* might be determined for some opportunities. When dollar values are essential, approximate relative values must be assigned a dollar value using one of the above methods.

Opportunity cost is a method that can be used to find at least a minimum value. This method is logically applied to areas withdrawn from multiple use and limited to a single recreational use. Thus, the value of the sum of the most valuable compatible uses given up to supply recreation use represents at least a minimum value of the recreation opportunity. For example, if timber values of $500 per acre are prohibited because an area has been restricted to recreation use, the recreation opportunity value would be at least $500 per acre. The recreation value, however, may be much greater than the opportunity value.

The method proposed for determining the indicated relative value of recreational opportunities involves combining three value factors: quality, substitutability, and use.

Quality is expressed as an *opportunity index* derived from the essential features and the attractions of the opportunity. *Physical and social substitutability* are combined into an index that together with the opportunity index rates the *uniqueness of the opportunity*. Uniqueness combined with use provides the *indicated relative value*. Use, however, is a combination of capacity for use and the percent of capacity actually used as illustrated in figure 1.

Opportunity Index

The concept of a recreation opportunity index (see box) assumes that the basic unit of recreation is an activity: what the recreationist does--his participation at a given place. Participation involves two sets of conditions: essential features and attractions. There are certain features or objects that must be present to permit successful participation in an activity. These can be called the *essential features*. For fishing, there must be water stocked with fish and access to the water although fishing success may vary. If the recreationist is satisfied to fish simply because he wants to catch fish, these are the only conditions he requires. Most people, however, like to participate recreationally in a pleasant place and probably be able to do other things, so the

			Number or code		Index		Value	
			Pre-fire	Post-fire	Pre-fire	Post-fire	Pre-fire	Post-fire
1. Essential feature rating								
a. Diversity (average rating)	Pre-fire	Post-fire						
2. Attractions:								
a. environment								
b. climate								
c. *wildlife*								
d. *geology*								
e. *biology*								
f. *landscape & scenery*								
Sum								
Average								
3. Opportunity Index								
1. Physical substitutability								
2. Social substitutability								
3. Substitutability Index								
UNIQUENESS INDEX								
1. Capacity class								
2. Percent of capacity used								
3. Use index								
VALUE CLASS AND ESTIMATED DOLLARS							$	$
INDICATED RELATIVE VALUE PROTECTED CLASS AND ESTIMATED VALUE							$	$

Figure 1.--*Sample form to determine indicated relative value and value protected for a recreation resource.*

attractions at a fishing site are usually deciding factors in *where* he participates. Thus the *attractions*, in addition to the *essential features*, strongly influence the choice of both activity and location.

By combining these factors, we can obtain an index of the quality of the opportunity. These factors can be objectively identified and rated so the index is relatively free from personal bias.

When rating an area for a given activity, it is possible that the quality of the essential features is not sufficiently good to ensure success, but there are many fine attractions. For such a situation, the point on the chart in the box would fall below the diagonal line (point B, for example). This would alert the appraiser to the fact that perhaps some other activity or group of activities might be better served than the activity at first selected. The area can probably support a diversity of activities. The further towards the upper right corner the point falls on the chart the more desirable the site for recreation. It probably means that it would be a popular place. In private ownership it would command a high price. In public ownership such an area would likely be heavily used, and would present many problems in administration to prevent conflicts of use, overcrowding, vandalism, and even public controversy over use. This estimate is then one expression of value.

When several activities[1] are possible on an area, it is logical to rate the site

[1]*One should be guided by what people do. The activity may be floating down a stream on an inner tube, collecting mushrooms, resting, climbing trees, watching hawks soar, throwing stones, catching frogs, hunting treasure, or making sand candles.*

Estimating Recreation Opportunity Index

Essential Feature Rating

1. Set down the essential features for the activity to be rated. Associated activities for a given attraction may be averaged giving a within-group rating.
2. On a scale of 1 to 5 (vertical scale) estimate the success the average participant could expect to realize from the given feature quality on the rating site. To do this use Appendix 1.--Rating essential features of recreational activity.

Attraction Rating

3. List the attractions for the site and nearby areas. Include environment and use at least five attractions if possible. If some are not present, this is not a concern. Exclude attraction most nearly corresponding to the activity being rated. This attraction should be rated as an essential feature.
4. Rate each attraction on a scale of five using Appendix 1.--Rating essential features of recreational activity.
5. Find the average rating of attractions (horizontal).

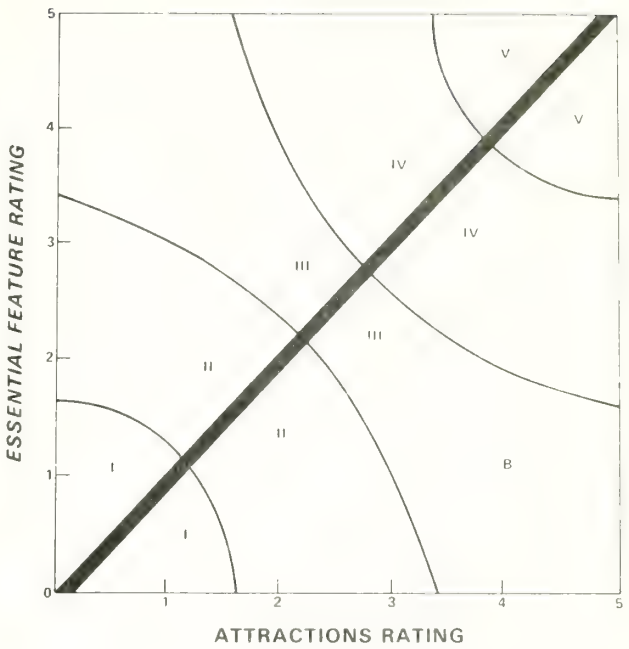
Diversity Rating

1. Rate attractions as above.
2. Use at least five recreation activities from two or more different kinds of attractions, but average the success rating for the vertical entry.

Opportunity Index

Find where lines produced from the calculated vertical and horizontal values cross. The roman numerals I through V rate the opportunity. I is poorest; V is best.

on the basis of its diversity. In this case, several attractions would be rated. Instead of rating the essentials for a single opportunity, however, the average of the success ratings for several possible activities would be used for the vertical scale entry to the chart in the box. Whenever a site rating falls beneath the diagonal line in rating a particular activity, therefore, it is well to consider the possibility of rating diversity.



Diversity is also the best way to rate unfamiliar areas, areas for inventory, and most campgrounds.

Diversity of recreation opportunities is of two kinds: (1) diversity of activities within a common attraction, and (2) diversity of activities among different attractions. For example: water attractions may support swimming and bathing, beach sports, boating, fishing, scuba diving, and outdoor living. Another site may have water, geological and biological attractions that will support water sports, spelunking, rock collecting, ecology study, bird watching, hunting, walking, and photography as well.

Recreationists form in general interest groups so the more successful the opportunities within a common attraction, more people of the group are attracted to the site. The greater the diversity of kinds of attractions, the greater the number of people from different interest groups will be attracted. Only the hard core of an interest group, however, need or want highly specialized essential features. Most recreationists have broad interests so they may even fall into more than one general interest group. The result is that increasing diversity is likely associated with a large increase in people served and attracted to the site with consequent chances for conflicts of interest and associated management problems.

In rating diversity, the essentials rating should include at least five activities from at least two different kinds of attractions. This lower limit to numbers of activities rated must be made or only the best would be rated, which would decrease the sensitivity of the index.

Most campgrounds have been developed around one or more attractions that provide opportunity for activities. Campground popularity and use will usually be some function of the successful activities that are possible on the site or adjacent to it. Thus campgrounds should be evaluated in respect to the activities that can be pursued on the site.

If a facility has been established specifically as a place for outdoor living, it should be rated for the activity *outdoor living*. If many activities are possible, rate diversity including outdoor living.

Substitutability Index

If a large number of different recreation areas and activities are available, the loss of one may not be critical. People will probably spend the same amount of time or money at another place or on another activity, and the loss to income is negligible. However, if the opportunities are very few in number and of high quality, the loss of one may be important because people may be prohibited from participating, or alternate opportunities may be overused. Substitutions or their absence are a strong factor in value determination (Knetsch 1971).

Social substitutability also seems to be a requirement in the appraisal because relatively low-quality recreation opportunities often serve an important need in a community and increases the value of the opportunity above the amount its quality normally would command. This is especially true for sites serving people unable to afford travel to better-quality opportunities further away.

Physical and social substitutability for the opportunity have been combined to broaden and strengthen the concept. A method for determining the suitability is given in the box.

Substitutability Index

Physical substitutability for opportunity (code)	Social substitutability (code)				
	1	2	3	4	5
1	I	II	II	III	IV
2	II	II	III	III	IV
3	III	III	IV	IV	V
4	IV	IV	IV	V	V
5	V	V	V	V	V

Criteria

Physical Substitutability Code

1. Many equal or similar opportunities locally and nationally for a single activity or for related or different activities. Some form is found in most all areas. Few, if any, limits to access or availability.

2. Equal or similar opportunity and range of activity common but poorly distributed locally, regionally, or nationally. Access and availability occasionally a problem, but not a significant limitation.

3. Equal or similar opportunity and range not common, but are well distributed locally and nationally. Access and availability may be a restriction to use.

4. Equal opportunity and range somewhat restricted locally but more common in some other regions. Access and availability may be a severe restriction.

5. Equal quality is very rare in any forested region. Maybe only one of a kind. Visitors come from far off. Unless in public ownership generally closed to public use.

Social Substitutability Code

1. Serves only a minor and incidental or unimportant local need. Nonessential.

2. Serves local population only, but not considered very essential. Loss would not be serious.

(Continued on page 1

(Continued from page 10)

3. Serves local needs very well and is needed here, but is only casually used by outsiders. Loss would be hard on some groups who use extensively but could not afford similar recreation at greater distances.

4. Important local need served. Loss would mean a severe restriction of opportunities in all groups. Frequently used by outsiders serving regional needs.

5. Highly essential to serve recreation needs locally, regionally, and/or nationally.

Uniqueness Index

The combination of Opportunity index (see box) with Substitutability index forms a further evaluation of the opportunity. Uniqueness indicates the supply or frequency of opportunities of different quality. If high quality is also very scarce, the opportunity commands a high value (Class V). If low-quality opportunities are plentiful, they are comparatively cheap (Class I). Other combinations are intermediate in value (Classes II to IV).

Uniqueness Index

Opportunity index	Substitutability index I	II	III	IV	V
I	I	II	II	II	II
II	I	II	III	III	III
III	II	III	III	IV	IV
IV	II	III	IV	IV	V
V	III	III	IV	V	V

Use Index

Use of an area for recreation confirms that a recreation opportunity exists and that the features constitute a recreation opportunity. However, we must also recognize that some unused areas have potential for recreation use. For damage appraisal, present use takes precedence over potential use. For planning, potential use and need must be recognized. For estimating value protected, therefore, potential use and value are logical considerations.

The Use Index combines capacity for use and percent of capacity used (see box). Carrying capacity is a concept that is difficult to express in precise numbers (Wagar 1964, Lime 1972) and no formulae to compute such numbers exists.

Carrying capacity is based on the capacity of the site to withstand use without degredation and the tolerance of people to crowding. Whichever limit is reached first establishes the capacity.

Paths, roads, and sanitary facilities, for example, all tend to increase capacity of a site to withstand use. But capacity can also be increased if users will tolerate lower standards of quality. Group activities have a higher tolerance to crowding than do individual activities. Thus, a swimming beach has a higher capacity per acre than wilderness use, hunting areas, or birdwatching.

When estimating Use index, highest ratings are given to areas carrying nearly full capacity use for the activity being considered. As use increases or decreases from full capacity use, the value rating decreases. Classes of capacity change in

Use Index

Capacity used (percent)	Capacity--annual visits < 500	500 to 5,000	5,000 to 50,000	50,000 to 500,000	500,000+
	Number				
40	I	I	I	II	III
41 to 80	I	I	II	III	IV
81 to 120	I	II	III	IV	V
121 to 160	I	I	II	III	IV
161+	I	I	I	II	III

multiples of 10; thus, the class ranges should be as precise as possible.

Actually, the value of an opportunity increases up to full capacity use. Thus, up to full capacity each user receives full enjoyment from the opportunity, the more users at full enjoyment the greater the total enjoyment--value of the opportunity. If the use exceeds capacity, however, the amount of enjoyment per person begins to decrease: consequently total value decreases, or increases very slowly, depending upon the rate of decrease in enjoyment.

Indicated Relative Value Class

The Indicated Relative Value class is obtained by combining the Uniqueness index with the Use index: class I is the lowest value; class V is the highest value.

Indicated Relative Value Class

Use index	Uniqueness index I	II	III	IV	V
I	I	II	II	III	III
II	II	II	III	III	IV
III	II	III	III	IV	IV
IV	III	III	IV	IV	V
V	III	IV	IV	V	V

Relative Value Protected Class

The Relative Recreation Resource Value Protected class (see box) is obtained from a dual rating of the opportunity: a prefire rating (before any fire occurs) and a potential rating which assumes that a fire causing maximum effects has occurred. The fire may not be of maximum intensity, but it must have caused a maximum effect on the resource.

Damage may not be larger than the prefire value rating. If, as may be the case for wildlife habitat, the postfire Indicated Value is greater than the prefire value class, benefits have occurred and the value protected is zero, or perhaps prescribed fire should be used.

A dollar appraisal may be made by simply applying a price per use-day multiplied by the number of users. The value per day suggested in "A Model for Determining Wildland Resource Values" (USDA Forest Service 1971a) is suitable but would be appropriate to use a range of values--a low figure for class I and increasing values for the classes II to V.

Relative Value Protected Class

Prefire class	Potential class I	II	III	IV	V
I	I*	**			
II	II	I			
III	III	II	I		
IV	IV	III	II	I	
V	V***	IV	III	II	I

*When no change in relative value results from burning, value protected is minimal.

**Blank cells represent fire benefit and hence no value protected.

***When the greatest loss can occur; hence, the relative value protected is greatest.

WILDLIFE RESOURCE

Concept

Conflicts in evaluating wildlife and wildlife habitat result from the complexity of biological and economic factors. The unresolved problems have often led to oversimplification in which some arbitrary amount of per acre damage has been claimed for every fire.

Although the relations between wildlife and value or damage most commonly have involved "game" animals and fish, these constitute only the more visable, sporty, or edible of the wildlife species that may be present. However, it is not reasonable to confine appraisal to "game" animals because (1) the maintenance of game animals in a habitat is so intimately related to food chains and the quality of the site to provide covers, and (2) both relate to the environmental considerations.

An animal habitat is an area combining water and food supply with cover for protection against weather and predators, and for resting, breeding, nesting, and playing. For most species, all these conditions must be found within an area that individuals of a species normally claim as their range. A proper balance of these conditions is needed for optimum habitat.

The natural animal component of any ecosystem is a unique product of the kind, size, density, and distribution of plants and other animals on an area modified by the climate and topography. The animal compliment is expected to change as the plant composition changes. Regardless of the existing type of plant community, however, compatible animal population can be expected to occupy the site. Disturbance on the site brings with it a probable adjustment in the character of habitat and a corresponding adjustment in the abundance and diversity of the animal population.

Fire is one such disturbance. Some animals may be killed or injured by fire, particularly the young and those species having limited mobility although whole populations are seldom if ever decimated by fires. Burning may also cause an abrupt and radical change in the vegetative character and the microclimate with a corresponding change in the animal compliment or a change in the vigor and abundance of the prefire animal population.

Temporarily, a freshly burned area may seem to be a biological desert. In some, new vegetation may be slow to develop, but almost immediately the animal compliment begins to adjust. A new balance of species, abundance, and vigor is established with the development of new vegetative situations. Because the vegetative state may also change rapidly in the first years following fire; the animal complement also can be expected to change but this change may lag the changes in food and cover.

The amount of fire-caused change in wildlife will depend in large measure upon the size and severity of the fire and the associated weather and climate. Regardless of the amount of change, however, the site still constitutes a habitat. Some animals can be expected to be compatible with the new habitat continuously trending towards a new balance. Moreover, some animals occupy all areas from which they are not artificially excluded.

Wildlife habitat resources differ from other wildland resources only because the primary product is different--wildlife is mobile and timber, forage, or watershed, for example, are not. Wildlands only become a habitat when they are stocked with compatible wildlife. *Thus the wildlife resource is a combination of habitat and wildlife breeding stock.* The ultimate economic product must be considered to be hunting, fishing, photographic activity, ecologic function, or the enjoyment and dependence on a quality environment, rather than deer, trout, or animals per se.

Specific objectives of local wildlife management together with desires of the people for wildlife as a part of the environment are needed to define the role of fires in respect to damage appraisal. These goals may vary.

Indigenous wildlife is legally the property and responsibility of the States while certain migratory wildlife has become a federal or international responsibility. *Wildlife* is thus *public* rather than *private* in nature and is managed for the public good, yet much *habitat is privately owned.* Public objectives for wildlife may or may not be coincident with private objectives of land (habitat) management. The opportunity for full wildlife management is best on public land, but broad public policy towards wildlife must be applicable to all ownerships because wildlife know no ownership boundaries and inhabit all kinds of land.

Most management has been aimed at manipulating ecosystems and regulating hunting, fishing, and predation for the purpose of favoring or discouraging game populations. Many kinds of nongame manipulations are also carried on to control pests or predators, although these are not generally considered to be "wildlife management". Moreover, marketing of most wild animals is illegal except for certain fish and furbearers. Thus, wildlife management unfortunately has become popularly identified with sport fishing and hunting objectives, which are distinctly recreational in nature.

However, some agencies now conceive the purpose of wildlife management to be that of maintaining a diverse population of animals. Expenditures are even made to maintain endangered species. This expands recreation uses from hunting and fishing alone to include nature study, birdwatching, photography, painting, and other forms of wildlife enjoyment and recognize the environmental values of wildlife.

For monetary evaluations, we are strictly concerned with the effects of

fire-caused changes in wildlife and habitat on human goals. When we recognize the existence of animals in the environment for the sake of the benefits humans derive from a "whole" environment, the existence of certain animals and, thus, of their habitats, has economic significance.

Unfortunately, there are few good guides to wildlife habitat quality or to the expected carrying capacity of different habitats. Some agencies have tentatively set up standards of desirable balance of vegetation types to meet certain wildlife objectives. Using these, the effects of fire can be judged beneficial or detrimental depending upon whether the fire moves habitat conditions towards or away from defined optimum balances. If the postfire trend is toward a poorer balance, damage has occurred and may be measured by the costs to rehabilitate the habitat. Precise statements cannot be made, but the following can be used as a guide. When a change of 20 percent or more in type conditions by area occurs in a habitat-range, the case should be carefully studied for either benefits or damages. Thus, to be of significance the size of fires may range from 1 to 2 acres for rabbits, to 200 to 300 acres for deer and turkey, and larger for some other species and many predators. For most purposes, fires of less than 10 acres could generally be ignored in wildlife damage appraisal.

Because the boundaries of a habitat cannot be accurately drawn and the size of animal range units varies widely, it is probably sensible to relate wildlife habitat appraisal units to timber management units. Timber management, moreover, usually has more influence on habitat than any other form of planned forest resource management. This means that wildlife appraisal units could be defined as ranging from 500 to 2,000 acres.

Appraisal

Because wildlife does not exist naturally independent of its habitat, it is not logical to evaluate wildlife apart from habitat. Attempts have been made to find the value of game and fish taken by sportsmen. On the premise that the game is worth at least as much as sportsmen are willing to spend to take the game, value figures have been derived by dividing estimates of the total amount spent by hunters or fishermen by the numbers of game taken. An estimate of the value of habitat as a producer of *game* could be made by capitalizing the total amount spent if the annual take and costs remained about the same from year to year. An estimate of capital value per acre of habitat could be obtained by dividing this capitalized value by the acres from which the game was taken. Such figures obviously only represent an *average* value per acre or per animal taken on the total area sampled. The estimate of *damage* would represent the decrease in capital value per acre.

On a Statewide basis, unless an extremely large amount of habitat were burned and the habitat greatly reduced in productivity, the computation would be unlikely to show significant decreases in value of wildlife and habitat. Gathering adequate information for small areas would be difficult and expensive. Moreover, it would be illogical to claim the capital value per acre as a loss from fire because the habitat is not often destroyed but only changed in quality. This change could be either for better or for worse, depending upon the human goals for its use.

When it is necessary to claim a value loss for animals destroyed by fire, the above process may produce the most reasonable value obtainable. However, it should be pointed out that the value derived from this process applies to the game *harvested*, not to the value of any individual animal. Any one animal could have a much smaller value because usually only the increase in a population is harvested in any year, and the animals killed by fire may or may not have been harvestable. Moreover, the value is further inflated because it does not account for costs involved in producing the game (the costs of operating a game management division, law enforcement, and related activities).

Basically, a claim for damage to wildlife and habitat must relate to a decrease in breeding stock and/or habitat quality that reduces the capability of the burned area to serve the human objective for wildlife use and enjoyment.

The appraiser must first determine how attainment of the human goals have been altered and, if they have been changed, determine the value of the damage or benefit.

As with recreation resources, damage to wildlife and habitat relates to: (1) the amount of decrease in opportunity to participate in wildlife use and enjoyment, (2) demand for the opportunity, and (3) the cost to restore the habitat and wildlife population to its former or equal status. Opportunity loss should be handled as described on pages 8-10.

With respect to (3), the sample list shown in figure 2 might prove helpful. Damage may be estimated to include (1) any costs to restore the habitat and restock the breeding population if it has been critically reduced by a fire, (2) temporary cost to maintain wildlife, and (3) increased management costs less any benefits. The justification for this expenditure will depend largely on public demand as well as technical considerations. If the change affects environmental quality only, methods suggested on pages 17-18 should be applied.

Habitat restoration is not often undertaken following fires. When such measures are not taken, certain conclusions can be inferred: (1) the damage to wildlife and habitat may be insignificant or beneficial; (2) the change in wildlife and habitat has not affected human goals; (3) there is no wildlife objective or policy for the burned land, which indicates that wildlife is not important to management; (4) the costs of rehabilitation are greater than the expected benefits; (5) there is no way to restore the former habitat although the new habitat can serve a different purpose very well; or (6) there are no funds available for rehabilitation even though it is needed.

Restoration costs should not be claimed as damage unless the restoration is to be done. If, however, there is expected to be a significant reduction in recreation opportunity relating to the fire, damage may be estimated in terms of appropriate recreation opportunity lost.

Damages claimed by individuals or others must relate to loss of income resulting from the reduction in wildlife numbers or diversity. Such loss may be properly charged as a local loss of income although there may be no loss in National income because the same amount would normally be spent by sportsmen in other areas.

Value protected will be the amount of such costs on area in which unfavorable fire effects can be expected. If fires can be expected to cause little change in the habitat quality, or to improve it, little or no value protected can be assigned.

Relative value of the wildlife supported recreation opportunities may be

Effects of fire on:

(Estimate)	Immediate effects (0-5 years)			Long-range effects (5 years+)		
	Adverse	No chg.	Favorable	Adverse	No chg.	Favorable
a. food						
b. cover						
c. breeding and nesting						
d. change in cover distribution						
e. change in recreation use						
f. overall effect						
g. predominant effect: Immediate				or long range		
favorable				or unfavorable		

Costs to restore habitat to an adequate level (if desirable):
a. treatment costs:
b. population maintenance costs:
c. animal restocking costs:
d. estimated number of animals killed and value/unit

Figure 2.--*Sample form to use as a reminder list for appraising wildlife habitat damage.*

estimated by means of the system on page 12. A change in relative value owing to fire may also be indicated by means of a before and after fire estimate.

Lacking any other means to appraise wildlife habitat value protected, a simple statement of urgency may be as useful as any evaluation. Such a statement must include: (1) the objective of wildlife habitat management, (2) the importance of meeting this objective, (3) how fire could cause failure to meet the objective, and (4) the relative urgency to control fire in the habitat so that the objective can be achieved together with an estimate of the size of permissible fire.

On areas for which there is no objective, the appraiser must assume some broad objective to make an appraisal. This will usually be in terms of public good related to the presence and maintenance of wildlife and wildlife diversity.

NONFOREST VALUES-AT-RISK

Concept

Nonforest values-at-risk refers to those values that are independent of forest resource values. Generally this means values that have been introduced into the wildland setting and not derived from it. Among the more obvious are buildings of all kinds from homes to factories, and such improvements as bridges, roads, powerlines, and fences. Another set of values relates to people, especially to residents and their activities--human safety and health; discomforts and inconveniences; traffic hazards and delays; energy consumption; and increases in crime.

Appraisal

Damage to property and improvements is logically appraised by current market prices, by repair or replacement costs, or, if unneeded in the future, by depreciated capital values. There may be cases where an item of property is unwanted and unneeded and its destruction is desired, in which case the fire may have performed a service. In such cases, cause and effect should be carefully studied to be sure the wildfire was not caused by intentionally burning the property.

There is no appropriate way to directly estimate the value of a human being, his safety, or health as such. However, approximations, based on such tangibles as loss of income, medical and hospital expenses, may be used to estimate damages.

Wildfires may cause numerous temporary discomforts and inconveniences to residents and travelers. It may result in cost due to traffic hazards and delays, heavy smoke on highways and airfields that may result in accidents, rescheduling of common carriers, as well as local traffic. At times heavy smoke over settled areas and cities has resulted in an increased demand for electric power for lights, water pumping, and other energy uses during fires. Where people must be evacuated from endangered homes, the prospects of vandalism and theft may require special police or the National Guard.

When any of these effects occur, the costs generated are logical inclusions for damage appraisal. Some of these costs are relatively straightforward, such as the cost of additional police officers, or accidents resulting from smoke-caused reduced visibility. Others are difficult to estimate, such as the increased amount of energy used or the cost to airlines to reroute or reschedule commercial flights. Probably only the most clearcut items would be included in a claim for damages in a trespass case, but consideration should be given to the others in any statistical compilation of damages and in planning.

The value protected for nonforest values-at-risk would be the estimated costs and losses that may be incurred as a result of some major fire situation affecting a given community. Estimates of the value of endangered property and improvements would undoubtedly comprise the most realistic part of the appraisal in dollars, and the assumption could well be made that the full value of the property is subject to loss.

In respect to public safety, the estimate should probably not be made in dollars, but rather in terms of potential risks involved. This may include consideration of numbers of people threatened, the capacities for warning and evacuation, the possibilities for entrapment, the nature and frequency of possible fires,

and the occurrence of weather conditions conducive to disastrous conflagrations. In some instances, ensuring public safety may be so overriding in importance that it becomes the major task confronting the fire-control personnel. If this is the case, all other values-at-risk are of secondary importance and regardless of the high values that may be involved they only contribute to the urgency, rather than create it.

ENVIRONMENTAL VALUES-AT-RISK

Concept

Environmental values are complex and require special analysis. Despite the somewhat vague references often made today to "environmental" deterioration, an appraisal of damage to the environment must be more specific. The purpose is to find out how fire-caused changes in the environment affect human objectives, well being, and financial status. The transitory effects on people while a fire is burning would best be appraised by methods described in the chapter on Nonforest Values-At-Risk.

Environments, for our purposes, can be described in terms of air, climate, soil, water, vegetation, and wildlife, and to some extent the interactions among these such as ecological status and scenery. Like watersheds, which are everywhere over land areas, every place has an environment.

Natural or seminatural acceptable environments differ in composition and quality. Generally, natural states are favorable and form some standard of quality. Reduction in quality is caused by degredation in such forms as visual, atmospheric, water, thermal, or chemical pollution. Efforts are now being made to set acceptable limits to air, water, and noise pollution. These are related to objective animal, vegetative, or even industrial tolerances, but visual pollution is subjective and affects individuals differently.

Moreover, different environments are conducive to characteristic life styles, whether woodsman, farmer, or urbanite. Each group has adapted to a different environment although each environment is life sustaining and presumably satisfies its indigenous group. Each group would resist abrupt changes in its particular environment and groups placed in another environment would likely be displeased. Thus, abrupt changes in environments, caused by forest fires may cause unfavorable reactions and produce pollution in view of some groups, especially residents.

A fire, even a large one, rarely renders the environment completely hostile to human habitation except temporarily in close proximity to and during active combustion. But fire-caused changes may have important effects on human responses to the environment including even mental health problems. Visual changes possibly may dominate, but odors become different and objects dirty. Objects take on grotesque or ugly arrangements, diurnal air and soil temperature ranges increase, wind blows stronger, frost penetrates deeper, snow depth is greater, and snow melt occurs earlier.

Appraisal

Rehabilitation costs are inadequate as a base expression of environmental resource value. However, they do provide a useful dollar approximation of the value protected if one will recognize that the *environmental resource value* itself may be much greater. A direct comparison of resource value and value protected is impossible because meaningful dollar values can't be placed on the environmental resource and mixed value units are not comparable. Where rehabilitation costs are used, they are intended to express an opportunity cost value of the environment. Use of rehabilitation costs says that we must value the prefire environment at least as much as the cost to restore it. It may also mean that we consider it essential to maintain the quality of the environment, shortening the time of its incapacity and is worth anything spent to correct it. As a drain on the budget, it is a meaningful representation of reduction in National income.

Several methods have been proposed to rate the relative quality of scenery (Sargent 1967, Litton 1968, Twiss and Litton 1966). Rating pre- and postfire quality using such methods can be helpful in appraising the change in scenic quality. Moreover, where some forms of income depend upon visual quality, a loss of income from reduction in visual quality is one measure of damage. Another is restoration or relocation costs.

Subjective, nonmarket values are probably best judged by social and political expressions. These expressions take the form of public opinion, protest, and controversy. The objective of such tactics is to influence individuals, officials, or legislators and to express values. The final result is often a new law. Judicial decisions sought through civil suits are also being used to direct decisionmaking.

These pressures may be aimed at many objectives--increased protection, changes in policy, or more efficiency to conserve certain values-at-risk. Public clamor for more or better protection from fire to produce environmental benefits is an expression that these values are considered higher by some people than obviously valued by legislators or administrators. Thus some values are formed in nonmonetary terms in a political or public opinion "market".

The following questions may be suggestive of other considerations that may apply to a particular case in question. What are the local and regional attitudes toward the environment? Will *any* fires be tolerated? Are the critical effects of fires temporary, irreversible, or persisting? What special features are present?

Dollars are the most convenient measure for economic analysis and should be used as far as possible. But when dollars are meaningless and otherwise fail to fulfill the need to justify fire-control action, the appraiser should not hesitate to use narrative statements as value judgments.

Size and intensity of fires affect damage to the nonforest and environmental values-at-risk, but many conflicting factors are involved so that such statements as to the effect of size intensity cannot be confidently made. Property and human life losses may be high with even a small fire, whereas some large fires may not jeopardize much property or human safety. Environment will probably be little changed by a small fire, whereas the significance of the effects may grow rapidly with increasing size. High-intensity large fires distribute a large quantity of smoke over a large area, but may loft the smoke high enough to be only a minor irritant while smoke from a small, low-intensity fire may be more irritating.

Visual pollution following the fire can be annoying to residents and tourists, but much depends on the location of burned area. A large burn in a remote area may go unnoticed whereas a small burn along a highway or close to a village can be upsetting. Vegetation may respond quickly after a low-intensity fire in central hardwoods so the scars are well hidden by midgrowing season while a moderate-intensity fire in young pine leaves visual reminders for several years.

Thus the value-protected appraiser must estimate the kind and size of fire most likely to cause the most damage to the specific set of values-at-risk being appraised. Consideration should also be given to estimating the fire size and intensity thresholds at which damages begin.

Measures of damage for appraising changes in other environmental values are as follows:

Fire-caused damage to environmental values

A. Air pollution, visibility obstruction, chemical effects
   1. Increase in health costs
   2. Cost of traffic accidents
   3. Cleanup costs
   4. Increased cost of undiscovered fires
   5. Loss of vegetation and crops
   6. Increased cost of fire control

B. Water pollution
   1. Costs to restore pure water at prefire level

C. Soil change
   1. Loss of productivity of soil evaluated through loss of income
   2. Costs of restoring soil condition to prefire status

D. Climate change (usually microclimate)
   1. Restoration cost

E. Ecological state (natural balance of plants, animals, and soil)
   1. Costs to restore the site
   2. Losses owing to fire-caused change in environment

F. Human inhabitability

1. Cost to relocate people
2. Loss to community through voluntary removals, recreationists, etc.

WATERSHED RESOURCE

Concepts

A watershed has value owing to its ability to regulate the rate, timing, and quality of water delivered to streamflow and storage, and to regulate soil erosion. The watershed only receives precipitation and disposes of it through evaporation, transpiration, storage, and streamflow. The watershed, therefore, is a *water processing unit*. The watershed does *not* "produce" water, but it does affect water yield as well as ground water recharge and values related to soil erosion. Watershed behavior is responsive in varying degrees to fire-induced changes in vegetation, soil cover, and soil permeability. Fire-caused *changes* in watershed performance and their impact on people and budgets are of concern in estimating *damage* and *values protected*. We are not concerned directly with *water* resources, only with watershed performance. Watershed consideration must be given in every appraisal of fire damage and value protected even though it is inconsequential.

Every watershed exhibits a characteristic behavior. People living on it or downstream learn something about its behavior. They learn, for example, how high runoff peaks have been; how low the flow may be in drought; the quality of water and its complement of fish; and the amount and effects of soil erosion taking place. They learn to live with and depend on this behavior or they may learn to correct some undesirable aspects. We may assume that certain costs and losses are usually associated with this expected behavior.

Should a wildfire occur on the watershed, the damage it causes will be the amount of the *increase* in costs if any, above the prefire average, any unexpected rehabilitation costs, plus any increase in losses of crops, property, and improvements, recreation opportunities, etc., but these must be in excess of the normally expected costs and losses before the disturbance to qualify as damage.

Critical factors in appraisal of watershed damage are:

1. *Watershed essentiality.*--This is a demand factor. The essentiality of demands for water and watershed services can be graded from absolutely essential to desirable. A dependable supply of good quality potable water is an *absolute necessity* to support a population. The normal water quality from a given watershed is essential to sustain established fish life. A suitable watershed condition is often essential to control soil erosion. Stable water levels are *needed* for commerce, and stable water quality is *needed* for many industrial uses. Water is *desirable* for recreation purposes and amenities, but not absolutely essential.

Almost any increase in demand for water or for watershed services creates an increase in dependency on water yield or for the watershed to maintain a new level of population, crop security, public safety, fish life, or amenities. *Watershed essentiality* is used here in the sense of expressing an *inflexible or increasing demand for watershed services.*

2. *Susceptability of watersheds to change in behavior when burned.*--The watershed stability (capacity of watersheds to maintain normal behavior in spite of disturbance) varies widely--from very stable to very unstable.

A fire may kill vegetation and destroy the soil cover. This affects the capacity of the soil to absorb precipitation and resist soil erosion. The amount of precipitation reaching the soil is increased by a reduction in interception by vegetation cover and the capacity to hold added water is reduced because less of the precipitation received is removed by transpiration. These changes affect the rate and timing of runoff and increase soil movement permitting some soil to be carried into streams and deposited in reservoirs or spill over into lowlands in floods. The amount of change is further influenced by the size of the area burned and by the capacity of the stream channel to carry an increased flow of water and soil.

Susceptibility of a watershed to change in quality of function relates directly to the cost of supplying the watershed services if some constant or increasing requirements are assumed. Thus, to maintain a given quality of services may cost more if the quality of watershed performance is reduced. When attributed to fire, this additional cost can be construed to represent one aspect of the damage.

Effects of changes in watershed behavior on essential watershed services.-- Appraisal of damages amounts to an evaluation of the effects of changes in watershed behavior on the plans, objectives, activities, safety, and budgets of institutions and individuals that depend upon the watershed behavior. Thus, there are three categories of watershed damages (assuming a constant demand and essentiality):

A. Costs to restore and rehabilitate the watershed to prefire performance levels, or to provide temporary or permanent substitutes for prefire watershed performance.

    1. Land treatment costs (revegetation, soil stabilization, channel repair, bank stabilization, etc.).

    2. New construction costs to compensate for loss of watershed functions. (Water-treating facilities, reservoirs, dams, flumes, etc.)

B. The *increase* of costs and losses resulting from loss of watershed function: increases in costs of domestic water, road and bridge maintenance, repair or replacement of facilities and improvements, repair of equipment, supplies, and property caused by a change in watershed behavior.

C. Value of property, recreation opportunities, or business income lost or destroyed.

Any of these losses may accumulate over the period during which the watershed function is subnormal.

Other services, such as suitable fish habitat, navigation waters, lake shore, involve so many property owners or so large an area that they must be managed by common consent and objectives, a function that is typically political and governmental.

The *essentiality* and *stability* of the thousands of watersheds is highly variable. These two factors are very important in estimating damage and values protected. At one extreme are highly essential watersheds that are very unstable; at the other extreme are stable watersheds whose service if of little consequence.

Rehabilitation measures are routine in some areas but not in others. The absence of rehabilitation must indicate some value judgment. Either the watershed function is not changed materially by fires or the effects are ignored or not understood.

Appraisal

A comprehensive list of costs and losses is given in the sample form shown in figure 3. If such costs can be estimated directly from information about the burned watershed, no other process is needed to obtain damages.

Damages and value protected should be estimated using the same type of information. In appraising damage, only increased costs and losses made necessary because of an *actual* burn should be included. In appraising value protected, estimates are needed of the costs that would be necessary if the watershed would be burned by a fire that caused maximum loss of benefits to the appraisal unit.

Some costs or losses may affect other resources, such as recreation and wildlife. They may be included where most applicable, but should not be counted twice.

Probable maximum damage must be estimated for the entire watershed unit and divided by the acres to obtain the mean value protected per acre. Therefore, it is necessary to define the watershed unit area under appraisal and the probable size and intensity of the largest fire or the fire causing maximum damage.

Value protected per acre is not constant for all fires in a unit because (1) as the fire increases in size, its effects involve areas downstream from the burn; and (2) the accelerating effects generated by increased areas of reduced watershed capacity.

	No. Units	Cost/Unit	Total Increased Cost
A. WATERSHED RESTORATION COST			
1. *Land Treatment Costs:*			
a. Cost of revegetation.	A.	$	$
b. Cost of mechanical soil stabilization	A.		
c. Cost of restoring fish habitat	Mi.		
d. Cost of bank stabilization (rip-rap etc.)	Mi.		
e. Other			
2. *New Construction Costs:* To compensate for loss of watershed properties			
a. Water filtration & treating equipment & installation			
b. Reservoirs to compensate for irregular flow			
c. Dams, flumes, etc.			
d. Other			
B. INCREASED COSTS			
1. *Increased or New Maintenance Costs:*			
a. Cost of road repair & maintenance	Mi.		
b. Cost of buildings, & bridge maintenance	No.		
c. Cost to maintain damaged equipment	No.		
d. Other			
2. *Replacement or Repair Cost (any purpose items):*			
a. Personal Property			
b. Equipment & supplies			
c. Building, bridges, crossings, etc.			
d. Fish planting			
e. Irrigation facilities			
f. Other			
C. LOSS OF OPPORTUNITY, PROPERTY, & INCOME			
1. *Loss of Income & Property:*			
a. Temporary business income loss			
b. Permanent business income loss			
c. Crop loss (investment plus profit)			
d. Other			
e. Property			
2. *Opportunity Loss:*			
a. Recreation opportunity loss (including amenities, fish, bathing, boating, etc.)			
b. Living space environment loss			
c. Business opportunity			
d. Other			
(Describe loss & estimate cost if possible otherwise give relative value class when possible.)			
Total Loss and Cost			$
Average VP/A Protected			

Indicated value from sample form, figure 6._____

Figure 3.--*Sample form for estimating watershed damage or value protected.*

Watershed damage per acre varies with the size and intensity of the burn. For example, the damage per acre and total damage on a 20,000-acre watershed might vary as follows:

Fire size (Acres)	*Damage/acre* (Dollars)	*Total damage* (Dollars)
10	10	100
100	15	1,500
1,000	100	100,000
10,000	150	1,500,000
20,000	140	2,800,000

The $140 estimate is useful for comparison or combination with value-protected estimates for other resources on the same unit. It would not be representative of damage per acre on small fires, only of potential loss on large hot fires for which planning is needed and it would help to fix the objective of suppression for the unit. This is the value that is protected.

Selecting Watershed Unit Size and Size of Fire

There are no firm rules for delineating unit watersheds or for determining maximum fire size and intensity for appraising watershed value protected. Much depends upon past experience and on the status of management.

Management of watersheds to produce or maintain benefits is ordinarily a response to a need to preserve or enhance watershed performance. The intensity or level of management is predicated on stability of watershed performance and the essentiality of service. The level of management in practice may be a good guide to value protected as well as a help in defining the watershed unit for appraisal because it is probably more intensive on important watersheds that lack stability.

For example, management levels 1 and 2 in table 2 involve little or no recognition of watershed problems and provide only incidental unplanned attention to them. The exception might be that the extensive protection shown in level 2 may be specifically for watershed protection. Although serious watershed problems may be ignored, the principle fire-control planning problem is at the higher levels of planning and policymaking where decisions are made whether or not to protect these lands.

Management levels 3 or 4 are found on the bulk of wildlands both public and private. Watershed management tends to be passive--prevention of watershed deterioration is desired, but little or no manipulation is done to accelerate watershed benefits. There may be no watershed management program other than the incidental benefits accruing from fire control and

Table 2.--*Levels of watershed management*

Level of management	Land use objective	Protection	Regulation of land uses	Usual restoration after disturbance
1	None or speculation	None or very extensive	None	None
2	Vague or general	Extensive fire control	None or minor	None
3	Multiple or specific watershed function recognized but no active watershed management program	Intensive fire control; no distinction among watershed	Vague, may include rural zoning though not specific for watershed	Rare, only in special cases
4	Watershed management through multiple-use planning only	Intensive fire control; specifically recognizing watershed value protected	Other uses planned and regulated to protect watershed	Not routine but done when needed
5	Extensive watershed management at least a secondary objective and may be a primary	Intensive fire control	Regulated in favor of watershed	Definately routine but extensive
6	Watershed a primary or single use	Intensive fire control; perhaps even to trespassing	Strict regulation or exclusion of potentially harmful activities, vegetation may be manipulated to favor water yield or protection	Routine and thorough

management of other land uses structured to prevent watershed deterioration. However, a broad range of watershed stability, essential services, and uses is included so that some discrimination among areas is needed to guide modern fire-control planning.

Management levels 5 and 6 pertain where active watershed management programs are in operation to maintain or improve watershed benefits. Such lands may be located anywhere but will usually be found where watershed problems are somewhat critical, such as on rough topography, in dry climates, or where soils are highly erosive. Extensive or intensive management programs may be followed.

Where management levels 5 or 6 are in effect, watershed units are most likely already defined and qualified managers having good knowledge of the behavior of the watersheds are employed. Although values protected may not have been appraised, the managers should be in a strong position to make such estimates.

The principle problems of unit definition occur with lands under management levels 3 and 4, and with those management level 1 and 2 lands that may be considered for fire-control districts in the future.

Problems in unit definition arise because of the wide range of conditions found on land under management levels 1, 2, 3, and 4. Watershed management is seldom a major priority in land management on such lands, which indicates either that watershed problems are not serious or are not recognized. Nevertheless, there is a need to examine areas to determine relative values protected because of the wide range of soils, topography, land ownerships and uses, watershed dependency, the likelihood of patchwork protection boundaries with parallel agencies having fire protection responsibilities--perhaps on the same drainage. Fire control may be the only approach to watershed benefit production. It is important at least to single out those watersheds on which expenditures for fire control will return highest benefits even on a relative scale.

The first step would be to draw the drainage boundaries of a protection unit on a map. A simple classification of drainages could be developed from general knowledge of the drainages. The classification should be based upon the essentiality of the watershed function and the uses supported, and the topographic features of slope and length of slopes, soil and cover stability affecting the susceptibility to loss of watershed quality by fire[2].

From this classification of drainages, three groups can be set up (1) drainages having high essentiality and high susceptibility to loss of function; (2) drainages having low essentiality and dependence and high stability; and (3) drainages having intermediate characteristics. Because there are no apparent serious problems involved in the low essentiality, high stability drainages, these can be grouped into one large class of lands for which little or no special appraisal or protection is needed. These would be the lowest value-protected watersheds. The medium class may need some special protection efforts, but the high essentiality, low stability group needs to be examined in more detail. These will be the highest in "value protected" of the watersheds on the district and may require special efforts in planning for fire control.

A district might be all of the same class, for example, all plains with deep sandy soils, where the watershed characteristics might not be changed appreciably by fire. But another district might contain a variety of soil types, topographic characteristics, and dependence on the watershed.

The size of watershed units can be established especially for the higher relative value-protected drainages by combining small drainages into large logical units having as homogeneous characteristics as possible. However, the units should preferably not be more than twice the size of the largest major fire occurring during the past 20 to 30 years. Preferably, units should be limited to less than 30,000 acres.

This analysis should be carried out as far down the line of values protected as needed to ensure meeting protection objectives.

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[2] *Some administration units already have methods for classification.*

When the units are delineated, an appraisal should be made of maximum probable damage for maximum destructive fire size on the unit. The total estimate should then be divided by the area of the unit in acres to obtain a value protected per acre in dollars.

Costs to restore watershed functions and services and probable loss of benefits vary over the thousands of small watersheds. Costs are related to specific watersheds, the work that would be needed to restore them if burned, variations in costs of doing specific jobs, and to the urgency for making repairs. So, there is very little opportunity to develop general correlations among fire size and severity, rehabilitation costs, and losses in dollars for large areas. Therefore, valuations should be made on the ground for specific watersheds.

Estimating Relative Value Protected for Watersheds

Use the sample form shown in figure 4. If the computation is an estimate of damage from a given fire, information is recorded in the first set of columns headed DAMAGE. If the computation is an estimate of value protected, use the appropriate columns headed VALUE PROTECTED.

Estimates for the potential type of protection served by the watershed and for the potential type of property and investment value per watershed can be derived

ITEM	DAMAGE		VALUE PROTECTED		INDEX	
	Pre-fire rating	Post-fire rating	Pre-fire rating	Post-fire rating	Damage	Value protected
1. Type of service (Code)					XX	XX
2. Property value (Code)					XX	XX
3. Watershed Essentiality	XX	XX	XX	XX		
4. Hydrologic soil group (Name_____)					XX	XX
5. Storm precipitation					XX	XX
6. Soil cover class					XX	XX
7. Increase in runoff (table 4)	XX	XX	XX	XX		
8. Soil texture					XX	XX
9. Natural protection code					XX	XX
10. Soil permeability					XX	XX
11. Basic erosion factor (table 7)	XX	XX	XX	XX		
12. Land slope (percent)					XX	XX
13. Relative increase in erosion (table 5)	XX	XX	XX	XX		
14. Years to recover					XX	XX
15. Est. of total relative change in watershed behavior (table 8)	XX	XX	XX	XX		
16. Indicated value (table 9)	XX	XX	XX	XX		

Adjustments:
17. Channel capacity: Poor _____ Average _____ Good _____
18. Percent of watershed burned: _____
19. Location in respect to channel: >2 chains: _____ Adjacent: _____

Figure 4.--*Sample form for computing estimated indicated watershed damage and/or value protected.*

using table 3. The values given to the five classes of potential protection served (I-V) are selected in the order in which people would be likely to give up the service. The security of human life, for example, is more important than economic security. The current emphasis on amenities could cause some problem: if a choice had to be made between economic security and amenities, however, the pragmatic choice would likely be in favor of economic security and safety even though amenities might have a high value.

The potential property resource and/or investment value represents values that could be affected by a change in hydrologic behavior of the watershed. Property on or close to flood plain limits, fishing waters, crop lands, and improvements are examples of property and activities that may be affected. Here we are only interested in the *increase* in value jeopardized by a breakdown in watershed function. For example, of 100 percent of value on the watershed unit, 5 percent normally is subject to losses when the watershed is undisturbed. After a fire, the value jeopardized may increase to 8 percent. The increase in value jeopardized is 3 percent as a result of fire.

Table 3.--*Watershed essentiality (potential uses, security on the watershed or within downstream influence)*

Type of service provided (see code below)	Property value code				
	1	2	3	4	5
1	I	II	III	IV	V
2	II	II	III	IV	V
3	III	III	IV	IV	V
4	IV	IV	IV	IV	V
5	V	V	V	V	V

Type of service provided code:	Increased value of property resource and/or investment per watershed unit jeopardized by fire (in dollars):
1. Little or no security involved.	1. 0 to 1,000
2. Site productivity protected only.	2. 1,001 to 10,000
3. Protection of amenities: scenic and aesthetic values--non-contact water recreation such as boating, and some wildlife water.	3. 10,001 to 100,000
4. Economic security: industry and irrigation water, fisheries, and navigation, disposal water, water power, farms.	4. 100,001 to 1,000,000
5. Security of human life and health: domestic water, ecosystem maintenance, body contact recreation, flood protection.	5. 1,000,000 plus

Entries 4 through 15 of figure 4 relate to the susceptibility of the watershed to changes in hydrologic behavior if it is burned. It provides an estimate of the relative susceptibility of different watersheds to produce an increase in direct runoff (table 4) and soil erosion (table 5).

The estimated relative change (increase) of runoff is developed from the hydrologic soil groups[3], expected storm precipitation (2-year 24 hour storm), and change in soil cover class (table 6). The soil erosion increase estimate is developed from soil texture, natural soil protection, soil permeability, land slope, and cover change (tables 5 and 7).

Time to recover is used in combination with the maximum rating of either table 4 or 5 to obtain the total estimated relative change in watershed behavior (table 8).

Entry 16 in figure 4 is obtained by combining the watershed essentiality rating with the susceptibility to change in hydrologic behavior (table 9).

Limitations

The estimate is relative--not absolute. Actual damage and/or value protected must still be determined from restoration cost and property loss estimates made for the watershed. The main purposes of the relative watershed rating are (1) to direct the analysis of the situation, (2) to determine the relative justification for undertaking restoration costs, and (3) to guide planning. The ratings should be useful for planning protection to find the relative urgency for protection among different watersheds.

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[3]*USDA Soil Conservation Service. 1964. Soil names and hydrologic classification. USDA Soil Conserv. Serv. Nat. Eng. Handb., Sect. 4 Hydrol., Part 1 Watershed Plan.*

Table 4.--*Relative increase in direct runoff from burned areas*[1]

Fire-caused change in soil cover class[2]		Hydrologic soil group[3]															
		A				B				C				D			
		Storm precipitation (inches)															
From	To	1	2	4	6	1	2	4	6	1	2	4	6	1	2	3	6
II	I	L	L	M	M	L	L	M	M	L	L	L	L	L	L	L	L
III	II	L	L	M	M	L	L	L	M	L	L	M	M	L	M	M	M
III	I	L	L	H	VH	L	M	H	H	L	M	H	H	L	M	M	M
IV	III	L	L	L	M	L	L	M	M	L	L	L	M	L	L	L	L
IV	II	L	L	M	VH	L	M	H	H	L	M	H	H	L	M	M	H
IV	I	L	L	VH	E	L	M	VH	E	M	H	VH	VH	M	M	H	H

[1]Approximate value of entries: L = low increase in runoff--0.49 inch. M = medium increase--0.50 to 0.99 inch. H = high increase--1.00 to 1.49 inches. VH = very high--1.50 to 1.99 inches. E = extreme--more than 2.00 inches increase. NOTE: Direct runoff includes overland flow. The proportion of overland flow will increase in progressing form A to D soil groups, it is likely that relatively small amounts would be noted as overland flow whereas a larger part of the smaller increase would be overland flow with C and D soil groups. The relatively smaller increase in C and D soil is because these already have higher rate of yield and the soil exposure does not cause a large increase.

[2]See cover class descriptions and specifications, IV is best condition, I is poorest.

[3]Refer to soils classification.

[4]Obtain amount of storm precipitation from climatological summary for a given locality.

Table 5.--*Relative increase in soil erosion on burned forest watershed areas*

Basic erosion factor	Soil cover condition change		Land slope (percent)								
	From	To	10	20	30	40	50	60	70	80	90
1	II	I	L	L	L	L	LM	M	M	M	M
	III	II	L	L	L	L	M	H	H	H	H
	III	I	L	L	M	M	H	H	H	VH	VH
	IV	III	L	L	L	L	L	L	L	L	L
	IV	II	L	L	L	M	M	H	H	H	H
	IV	I	L	L	M	H	H	H	H	VH	VH
2	II	I	L	L	L	M	M	H	H	H	H
	III	II	L	M	M	H	H	H	VH	VH	VH
	III	I	L	M	H	H	VH	VH	VH	E	E
	IV	III	L	L	L	L	L	L	L	L	L
	IV	II	L	M	M	H	H	VH	VH	VH	VH
	IV	I	L	M	H	H	VH	VH	VH	E	E
3	II	I	L	L	M	M	H	H	H	VH	VH
	III	II	L	M	H	H	H	VH	VH	E	E
	III	I	L	H	H	VH	VH	E	E	E	E
	IV	III	L	L	L	L	L	L	L	L	L
	IV	II	L	M	M	H	H	VH	VH	E	E
	IV	I	L	H	H	VH	VH	E	E	E	E
4	II	I	L	L	M	M	H	H	VH	VH	E
	III	II	L	H	H	VH	VH	VH	E	E	E
	III	I	M	H	VH	VH	VH	E	E	E	E
	IV	III	L	L	L	L	L	L	M	M	M
	IV	II	L	H	H	VH	VH	VH	E	E	E
	IV	I	M	H	VH	VH	VH	E	E	E	E

[1]L = low, least amount of change in soil erosion; M = medium amount of change; H = high amount of change; VH = very high amount of change; and E = extreme amount of change.

Table 6.--*Summary of hydrologic cover condition criteria and classes*

Criteria	Prefire condition				Postfire condition			
Hydrologic condition	I	II	III	IV	I	II	III	IV
Bare exposed soil (percent) (F and H less than 1/4 inch)	>70	35 to 70	10 to 35	<10	90	40 to 70	10 to 40	<10
Litter cover:								
Depth (inches)	Thin	Thin	1 to 2	2+	All burned			
Coverage (percent)	<40	40 to 75	75 to 90	90	30	30 to 60	60 to 90	90
F and H:								
Depth (inches)	Very thin	Thin	1/2-1	1+	Mostly Burned		Part-burned	Intact
Coverage	<30	30-60	60-90	90	<30	30-60	60-90	90
A_1 horizon Depth if present (inches)	<1/4	1/4 to 1/2	1/2 to 1	1+	Little immediate change			
Forest floor weight (tons/acre)	<1	1 to 4	5 to 8	8+	<1	1 to 3	4 to 6	6+
Live vegetation cover	Thin	Moderate to well stocked	Moderate to well stocked	Well stocked	More than 80 percent dead or top-killed all sizes	Most saplings and poles dead or top-killed	Most saplings top-killed	Only smaller vegetation killed or top-killed
					>90 percent exposure	60 to 90 percent exposure	40 to 60 percent exposure	>40 percent exposure
					Annual and perennial herbs mostly all top-killed and some dead. Any fire.			

Table 7.--*Basic soil erosion factor estimate*

Soil permeability[1]	Soil texture[2]								
	Coarse			Fine			Medium		
	Natural soil protection[3]								
	2	1	0	2	1	0	2	1	0
Rapid (A)	[4]1	1	1	1	1	2	2	3	3
Medium (B)	1	1	2	1	2	3	2	3	4
Slow (C)	1	2	2	2	2	3	3	3	4
Very slow (D)	2	2	3	2	3	4	3	4	4

[1]If no better approximation of permeability is available, use the hydrologic soil group estimates A, B, C, and D.

[2]Soil texture: coarse = sand, gravel, sandy loam, loamy sand, sandy clay, sandy clay loam; fine = clay, clay loam, silty clay; and medium = fine sandy loam, silt loam, silt, loam, silty clay.

[3]Natural protection: 2 = site has 2 or 3 of the following characteristics: rocky surface (more than 50 percent rock cover); above average surface roughness, strong stable soil structure; 1 = site has only 1 of above characteristics; and 0 = none of the above characteristics present.

[4]Approximate factor values:
1 = soil loss less than 25 tons/acre/year; K = less than 0.25. 2 = soil loss 26 to 60 tons/acre/year; K = 0.26 to 0.35. 3 = soil loss 61 to 100 tons/acre/year; K = 0.36 to 0.45. 4 = soil loss more than 100 tons/acre/year; K = more than 0.45.

Table 8.--*Estimate of total relative change in watershed behavior*

Highest rating either increased runoff or erosion	Years to recover former watershed function			
	0 to 3	4 to 8	9 to 14	15+
Low	L	M	H	E
Moderate	M	H	VH	E
High	H	VH	E	E
Very high	VH	E	E	E
Extreme	E	E	E	E

Several local interpretations are needed, however, to narrow down the significance of the estimates. Damages will be affected by the area burned and how it is located. Area burned will affect both total effect and total damage. In estimating value protected, however, a burn covering enough of the watershed to cause approximately the maximum damage must be considered.

Table 9.--*Indicated relative value protected*[1]

Susceptibility estimate of total relative change in watershed behavior	Essentiality				
	I	II	III	IV	V
L	I	I	II	II	III
M	I	II	III	III	IV
H	I	II	III	IV	IV
VH	II	II	III	IV	V
E	III	III	IV	V	V

[1]Rankings are devised for stream channels having average characteristics. If channel is less than average or poor in carrying capacity, advance rank one class. If channel has much better than average characteristics to carry additional loads, rank may be decreased one class.

Indicated value-protected class	*Interpretation*
Class I	Little if any restoration costs justified and little property damage possible.
Class II	If susceptibility is high, essentiality is low and vice versa. Only small costs are justified and other losses light. Below average in value protected.
Class III	Same as II but at a higher level of essentiality or susceptiblity. Some restoration is justified but usually not done. Other losses only moderate.
Class IV	Occurs only on Essentiality Class III, IV, or V watersheds. Extra effort cost is justified. Many different items of cost class are indicated.
Class V	Both essential and susceptible. All useful measures should be taken to restore the watershed. Property losses may be high and all types of costs are possible and justified as needed. Highest value-protected class.

On steep watersheds with shallow soil and narrow, shallow channels, flash floods could occur with minor increases in runoff. On broad, flat watersheds with deep soil and adequate channels to carry flow, the same increase in runoff might hardly be noticeable--and would be expected over a longer period of time.

If the fire leaves a strip of unburned area along the stream, it is likely that much of the eroded material will be trapped in this strip and not pollute the stream. If the burn extends along the streambanks, the chance of stream pollution is greater. Moreover, if the streamside vegetation is killed, the chance of increased stream temperature is greater, which could change the fish habitat.

This relative value could be useful as a guide for (1) estimating lost benefits and justifiable restoration costs when estimating damage for specific fires, and (2) for a first estimate of value protected for inventory and fire-planning purposes. Approximate dollar estimates could be made by classifying watersheds into their respective relative indicated value classes and dollar estimates made for sample watersheds representing the classes. Actually, on a given forest or even section of the State, there should be some similarity in hydrologic behavior among watersheds of a given nature. The large differences will be caused by different physiographic and climatic conditions occurring between regions and in benefits or savings produced. The procedure would be most applicable to management levels 3, 4, and possibly 5 (table 2). Much better information should already be available for management class 6.

Unfortunately, there are no generally applicable precise formulae available from which the effects of forest fires on watershed behavior can be predicted. The variables are numerous and complex, joint effects are common and are not well documented (Settergren 1967). Moreover, the effect of watershed changes on the activities and values varies among watersheds.

TIMBER AND RELATED RESOURCES

Concepts

The timber resource is identified as those forest stands included in calculating allowable cut on managed forests or on unmanaged public and private forests. It does not include stands currently and potentially nonmarketable; those reserved from cutting by law, regulation, zoning, or withdrawn for other purposes; and stands physically inaccessable by acceptable standards for the coming rotation.

Stands permanently withdrawn from timber use are excluded from the timber resource (allowable cut base) although National emergencies could force a change in status: National Parks, some forest preserves, and wilderness areas. If timber loss must be estimated for these areas, possible future returns must be discounted for long periods of time resulting in very low loss. If salvage of fire-killed timber is done on such areas, the income must be considered as an unexpected increase in income rather than a loss. In most instances, no timber loss should be claimed.

Other losses, however, such as those for recreation that depend on the trees, may be claimed.

Timber related resource cover items depending on the value of the timber resource but not usually considered in appraising the timber resource alone: real and personal property, primary forest products destroyed (pulp pile, logs, etc.), and community values to labor, business, and residents.

Physical Measures Needed for Estimates

To estimate timber loss, determine fire-caused mortality as well as growth loss from all fire-related causes, which together are known as *growth impact* (USDA Forest Service 1958).

Fire effects on timber resources may include: killed or top-killed trees, bark and outside wood charring, injuries to surviving trees that could cause degrade and volume loss in later years from disease and insect attacks and increased branching due to stocking level reduction, soil exposure with possible effects on physical soil characteristics affecting seedbed and site characteristics, undesirable changes in species composition in future natural stands, and failure to restock to desirable species requiring treatments to reestablish growing stock.

Timber survey methods are well known to practicing foresters and need not be elaborated here. Any system that will develop information on the mortality of merchantable trees and growing stock and show the effects of fire on young growth and future volumes and quality should provide the needed information.

Perhaps the most comprehensive method for obtaining field data and computations of fire-caused timber volume loss was devised by the USDA Forest Service Survey Section. Detailed instructions are contained in *3152.42 Handbook on the Appraisal of Fire Damage to Timber on Protected State and Privately Owned Commercial Timber Lands.*

The principal challenges in making the physical survey are (1) to identify soon after a fire potential future volume and quality reduction in surviving trees, and (2) to predict the ensuing stand and its merchantable volume during the coming rotation. Unfortunately, few foresters have opportunities to develop the experience to do this and must rely on available research and/or local experienced people. A list of appropriate references is included in Appendix II.

Predicting the stand expected to follow a fire is difficult. Successful natural regeneration varies with species, soils, climate, and especially macro- and microclimate variation immediately folowing the fire. In some localities, regeneration is fairly certain; in others, it is very unlikely. The general probabilities should be fairly well known in a locality. Appraisers should make it a point to learn how forests in the area respond and how this response varies with fire intensity.

Site deterioration is an aspect of fire damage about which too little is known. It is also likely to be overrated. There are glaring examples of site deterioration such as the loss of organic soils on which vegetation has survived. Perhaps fires on coarse soils where the organic materials are not plentiful or rapidly recycled and vegetation is slow to reestablish represent situations where fires may reduce site quality mainly through the loss of nitrogen and nutrient necessary to start a new cycle of vegetation.

The most probable effects of fire on site quality relate to changes in soil nutrients, soil physics, including moisture relations, and microclimatic effects. Such effects as the release of minerals held in deep mor humus in cold climates have been shown to be beneficial. Moreover, there is little proof that fires in general reduce site quality.

Injured Stands

Injury is perhaps a greater cause of damage in hardwood than in conifer stands. Typical fires in hardwood stands are lower in intensity and less apt to burn in the crowns than fires in conifer stands. The result is that injury is high in hardwoods and mortality is high in conifers.

On medium sites, the critical period for hardwoods is when the trees are 30 to 60 years old, while they are in the large pole and small sawtimber sizes. At an

earlier age, while the trees are of seedling and sapling size, injured trees will often outgrow wounds and produce little degrade in quality of logs (Loomis 1973).

Older and larger trees are less vulnerable to injury, and have salvage value. Moreover, if salvaged before wood rotting has begun or while confined to the sapwood,[4] little loss will occur because injured wood will be slabbed off in the waste. Principal losses will be due to harvesting smaller-size timber, which may reduce stumpage price as well as volume. It may be necessary, however, to hold the injured trees until they can regenerate a new stand particularly if regeneration is dependent upon seed.

Economic Measures of Damage

Timber damage and value protected can usually be appraised more accurately than other forest resource damages because of better market and product measures, although there are uncertainties to consider. Loss of income is the difference between the present value of the expected net pre- and postfire returns from sale of stumpage where salvage is included in postfire returns. The methods of appraisal may be direct market value, conversion return, discounted net value of future returns or conversion returns, and, in some instances, replacement cost.

Other items that may be appraised in estimating timber and timber related damages are as follows:

1. Costs or increase in costs as a result of fire to:
    a. Reestablish stands that would not have been required without fire.
    b. Sanitize burned stands to control insect and disease outbreaks.
    c. Other timber stand improvement to remove unmerchantable fire-caused cull and potential cull and to increase desirable species and growth that would have been unnecessary without the fire.
    d. Reduce fuel hazard increased by the fire.
    e. Increased administrative costs to revise and carry out the management plans.
2. Loss of primary forest products destroyed by fire such as pulpwood, logs, bolts, posts, and poles[5].
3. Loss of timber-related improvements and equipment used in timber harvesting.
4. Community losses, including loss of jobs that cannot be replaced or income of suppliers and service industries.

Streeby outlined the major constraints and suggested methods for estimating timber damage in each case. The major constraints are marketability of timber, planned cutting date, and kind of management.

Streeby designated market conditions as *full allowable cut sold,* and *full allowable cut not sold.* Full allowable cut sold is described as an approximate balance between stumpage supply and demand, or as an excess of demand over supply. This does not assume temporarily depressed markets or cyclic situations, but rather situations where competition for the supply has been and is expected to continue strong. The case is usually characterized by bid prices higher than minimum acceptable appraised prices of stumpage. It also applies to areas of young timber of desirable species and quality that are expected to have good markets when they reach merchantable size. Markets for species may vary on the same areas, but it should not be difficult to designate areas and species on any protection area filling these qualifications. Probably the bulk of all timbered areas in the United States fall in this cagegory.

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[4] *The time available for salvage with minimum loss from degrade varies with species, climate, and infection opportunities. Wood rotting tends to develop faster in warm, moist climates and is slower in cool, dry climates. Insect attacks that kill and weaken trees may begin very quickly. Local considerations will govern the decision.*

[5] *Ownership in items 3 and 4 must be considered in estimating* who *loses, but for planning purposes it is immaterial who loses if the values are at risk.*

Where this condition applies, timber stands injured or destroyed by fire can be valued by using market price. Young stands below merchantable size, however, should be appraised by discounting future returns, or by replacement value. In any case, the value of salvaged material should not be claimed as damage. Moreover, if the next rotation harvest is advanced or brought closer to the present because of the fire, an adjustment should be made for the changed timing of the next harvest cut and returns. In many cases, the effect on the appraisal is small and could be ignored.

Full allowable cut not sold is characterized by a stumpage supply greater than the demand so that not all the allowable cut is used or sold. Bid price is usually close to or the same as appraised price and competition is weak or nonexistant. Some offerings are not sold and some merchantable-sized stands are not even offered for sale.

Markets are subject to change--sometimes suddenly--because of new technology, shortages in more desirable species, changes in accessability, or entry of new capacity for use.

Damage to such markets should not be large. The two market conditions shown in table 10 are possible: (1) timber sold before being burned or is burned during harvest, and (2) timber is not sold before the fire. If the timber is not sold, it may be salable now at minimum price or it may be merchantable at some future time. If it is never expected to be merchantable, it would not be included in the allowable cut base.

If the timber is sold or in process of harvesting, any damage should be appraised on the basis of the sale price as in the case of full-cut-sold. If timber is plentiful and a less valuable stand is substituted for the burned stand to complete a sale, the difference in value of the two stands is a measure of loss of income.

If a substantial part of a rotation is expected to elapse before the timber is marketable, new growth may replace the trees burned before they are needed, thus, no loss of income would occur. If, however, the timber would become marketable in the future and because of the fire is then not suitable, the discounted expected future net returns would be the base for claiming damage.

At present this case applies mostly to inaccessible stands, stands of low volume and quality, and stands of presently unmerchantable species. Some good site, low-quality stands could benefit by a fire that destroyed the unmerchantable trees if a new stand was established.

Planned or estimated date of cutting distinguished between cuttings planned or contracted for the current year from timber to be cut in the future up to a rotation or more hence. Current year contracted cutting should include the period through the time the contracted price for stumpage is valid.

Damage to timber contracted for sale during the first year of the contract (beginning with sale preparation) can be appraised at market prices. Timber to be cut in the future should be appraised at the discounted value of future net returns. Young timber having merchantable value, however, may be appraised at the present market value even though growth in volume and value may have been expected to make the stands more valuable in the future.

Kind of management must distinguish between even-age, and all-age management because this influences the technique of estimating damage. In even-age managed stands loss of seedlings, saplings, and even pole-size trees that are substantially smaller than the average of the stand does not ordinarily constitute damage. In all-age managed stands, however, each age and size class of trees is needed in the stand at all times, hence the loss of the smaller trees at any time constitutes damage.

It is particularly important to avoid overappraisal of stands for which only a future market exists and to avoid appraising timber loss on forests withdrawn from the market.

Value Protected

The whole timber value that is at risk in the worst fire that may occur determines the value protected, however, a lesser value based on the worst probable

Table 10.--*Methods for appraising damage to timber*[1]

Kind of Stand and Planned Cutting Date	Method: Full allowable cut sold	Method: Full allowable cut not sold
EVEN-AGE STANDS		
1. Seedling-sized plantations	(1) Replacement cost + (2) Loss of growth (years since planting).	(1) Replacement cost if advisable. (Planting may not be a viable option for timber, but may have other values.)
2. Sapling or pole sized but currently unmerchantable sized plantations	(1) Market value of similar stands (transaction evidence) less land value if separated. (2) Discounted future net returns adjusted for timing of rotation. (3) Cost value. (4) Replacement cost.	Same as for Full Allowable Cut Sold except no loss if natural reproduction will form a suitable stand by the time it is needed.
3. Immature and presently less than merchantable size natural stands.	(1) Market value of similar stands (transaction evidence) less land value. (2) Discounted future value of returns with adjustment for timing of rotation.	No loss if stand and growth will likely be replaced naturally before needed. (1) Costs of sanitation, timber stand improvement, and probable hazard reduction.
4. Early merchantability stand. a. pulp stands b. nonpulpwood (no current cutting planned)	(1) Stumpage market value minus salvage with adjustment for earlier next rotation. (1) Stumpage market value minus salvage adjusted for rotation. (2) Discounted future value minus salvage adjusted for rotation. (Use when large growth in value is expected.)	No loss if replacement is expected by time stand would be harvested. Otherwise same as for Full Allowable Cut Sold.
5. Mature or near mature stands. a. to be cut now b. future cutting planned	(1) Stumpage market value minus salvage. (1) Stumpage market value minus salvage. (2) Discounted net future value at planned harvest minus net salvage and adjustment for earlier rotation.	(1) Market value of stumpage minus salvage. (2) Loss from substituting another less valuable stand to protect purchaser. (1) Discounted reduction in net harvest returns minus net salvage. (2) No loss except for sanitation or timber stand improvement if full cut is not expected during this rotation.
ALL-AGE STANDS		
1. Managed and regulated a. full salvage required b. no change in cutting routines	(1) Stumpage market value minus salvage adjusted for irregularity in future returns. (1) Discounted expected returns without fire minus expected with fire returns	(1) Situation unlikely to occur. (1) Same.
2. Unmanaged	(1) Stumpage market value minus salvage.	(1) If marketable now, prefire market value minus salvage only. (2) If marketable only in distant future, discounted without fire minus with fire net future value.

[1]Add the fire-caused costs of management, timber stand improvement, or hazard reduction as appropriate in each case.

fire is sometimes used in planning fire control action.

Value protected can be estimated by using the same methods suggested for damage appraisal to establish the present value of forest stands less salvage following fires. A broad average value per acre for a large protection unit or even a State may be obtained using rough methods. However, such appraisals do not provide the value discrimination among resource units needed for planning protection on small planning units. It could be prohibitively costly to make detailed appraisals for all resource units in a protection area.

If we assume, however, that the value classes ($250 to $500 per acre) being used by the USDA Forest Service reflects approximately the range of value differences that can be correlated with significantly different levels of fire control, it would

not be necessary to appraise differences less than $500 for estimating timber values for resource units in value protected. Because this is not a very sensitive value separation, appraisals can be approximate without loosing significance.

Even-Age Management

For estimating standing immature timber value, discount to the present the expected net stumpage return per acre at maturity as follows:

$$PV = \frac{FV}{1.0p^n} = \frac{\text{Expected Future Value (FV)}}{(1 + \text{interest rate})}$$

If fire-killed timber is not salvageable because of the fire or because it is not marketable (too young), the timber loss (value protected) would equal its discounted future value at full maturity. *If the timber is salvageable*, the value would be present value minus salvage (PV-S). For example, merchantable products begin to be produced at age 40, and full salvage of burned timber is carried out. The salvage value increases with age of stand; therefore, the potential value protected is reduced as the stand age increases. At rotation age, the salvage is approximately equal to rotation income and loss approaches zero if salvage value is not reduced below normal market value by the fire.

In general, the value protected for most even-aged stands that can be salvaged is highest during the period just before merchantable products are first produced. If the timber is rendered unsalvageable by the fire, however, the value protected increases throughout the rotation and is greatest if killed at full maturity.

This method of finding value class or the actual approximate value is illustrated in figure 5. The example shows the value protected from a fire that occurred in the 60th year of a stand being managed on a 100-year rotation for which final yield (including intermediate cuts) would have amounted to $1,700 per acre (5 percent present value).

Follow the 40 year vertical line until it intersects the 5 percent present value (PV) line, then follow horizontally to the $1,700 value line (top scale). Thus the value is now Class I. The dollar value of the income would be $1,700 x 0.14 (multiplier in left axes), which equals $239.00. Salvage of $50 per acre is anticipated; therefore, value protected would be $189 per acre ($239 - 50). Addition of values protected for other resources could raise this figure.

If the value protected estimate is made at the beginning of a 10-year planning period, the value at the end of the period should also be estimated. In 10 years, only 30 years would remain till harvest. Therefore, the stand may have increased to a Class II stand unless possible salvage value has also significantly increased. The year during the planning period for which value protected is to be estimated must be decided.

All-Age Management

The value structure for all-age managed stands differs from that for even-age managed stands. A *cutting unit* of a *regulated all-age* forest maintains its present value as shown in figure 6. Any cutting unit of a fully regulated all-age live stand reaches a maximum value just before and a minimum value just after periodic cutting. The range of value varies with price, rotation length, cutting cycle, and interest rate. The value of a fully *regulated all-age forest* where annual cuts are made may remain constant, but the value of any cutting unit fluctuates within the cutting cycle.

A fire in all-age forests may kill trees of all ages, although mortality probably decreases with increasing tree size. Loss of immature trees creates voids of mature trees at some future date that either must be replaced with trees from other sources or by skipping all or part of a harvest cut. In even-aged stands, however, the loss of young understory trees from middle to older age stands is often a benefit because they are not wanted until the new stand is being reestablished.

Thus, managed all-aged forests maintain a relatively constant value and value protected. The value protected varies with vulnerability of the stand to damage (young tree species), volume, stumpage price, and fire intensity. Because cuttings are regular, slash may usually be present although more scattered and never as heavy and hazardous as in the clearcut even-aged stands.

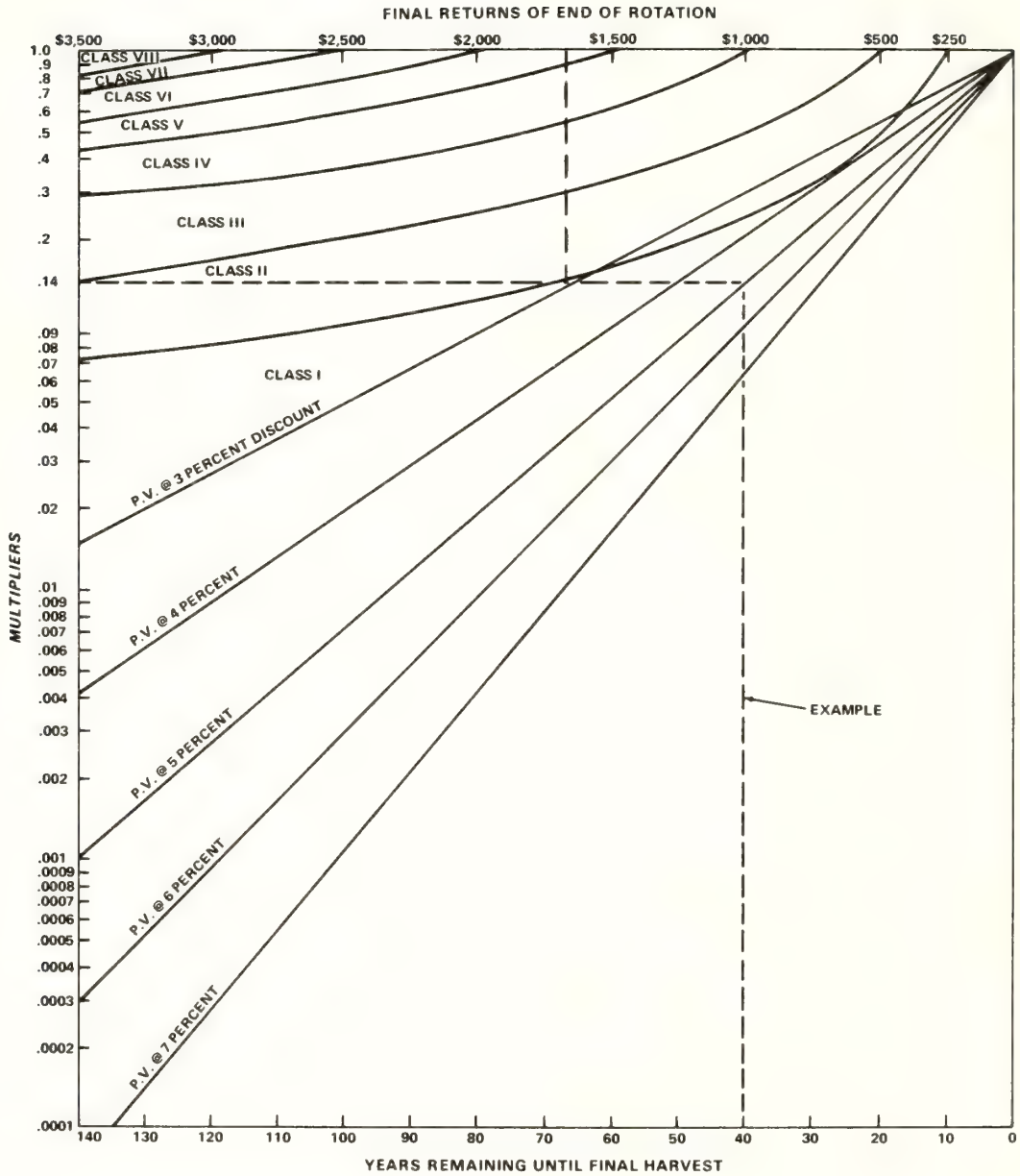

Figure 5.--*Value and value class for estimating value protected even-age management young stands (per acre).*

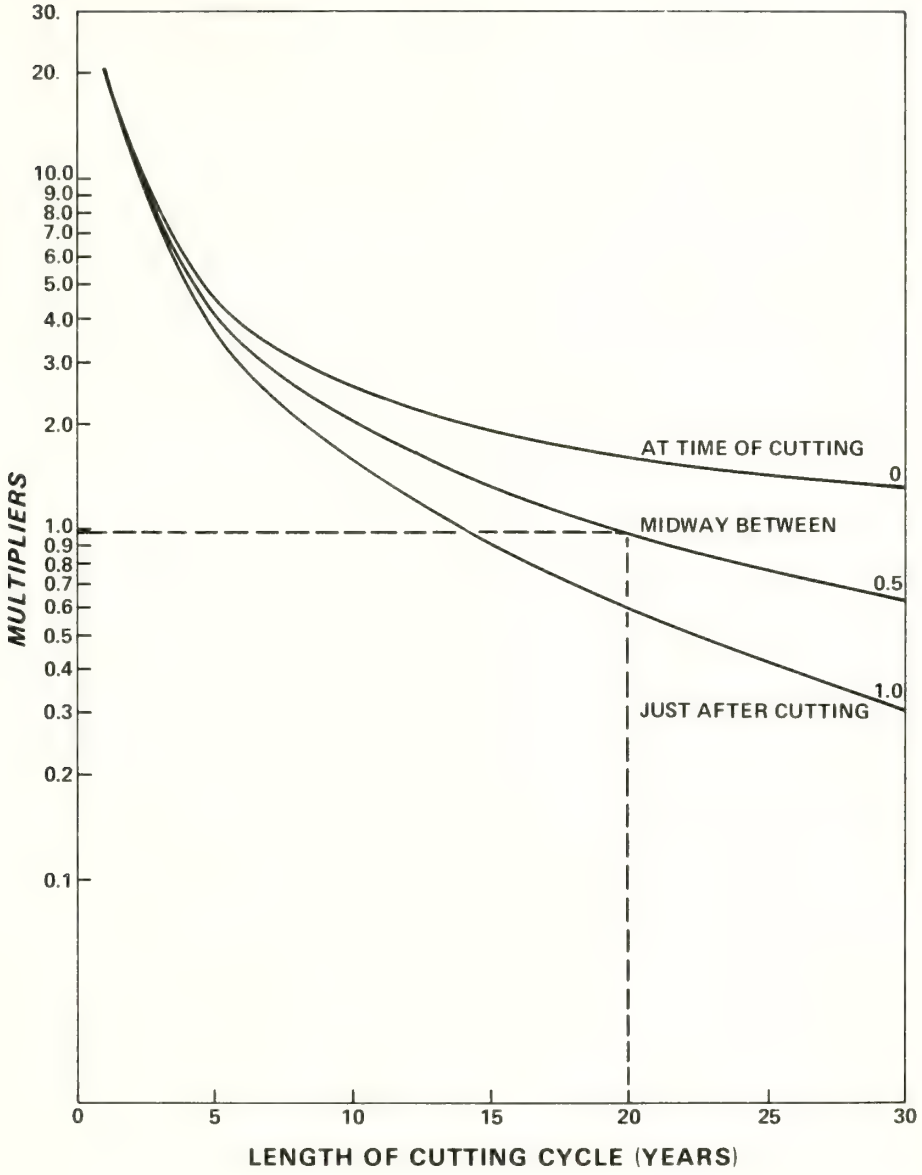

Figure 6.--*Multipliers of expected net income from cutting unit to find present value of an all-age managed cutting unit using a 5 percent discount rate. Example (dashed lines): Each 20 year cutting cycle yields $100 per acre net return from a cutting cycle unit. To find present value (PV) at 1/2 cutting cycle multiply $100 by 0.985, which equals $98.50 per acre.*

Relations illustrated in figure 6 and table 11 can be used to appraise value protected for all-age cutting units. A given periodic net income from a cutting unit and cutting cycle interval (horizontal scale), times the multipliers (vertical axis, fig. 6) will give the present value of future income of the cutting unit at 5 percent interest (Lundgren 1971, table 4). If all the cutting units in the regulated forest are considered, the value of the property would be the capitalized value of 1 year's net income. A fire-control planning period may be less than, equal to, or more than one cutting cycle; therefore, the midpoint value of a cutting unit may be most appropriate for planning use. If the full allowable cut is not expected to be made, the appraisal is made differently.

RANGE RESOURCES

Concepts

Forage--the range product--is essentially an annual crop and for more than most forest resource the effect of fires is seasonally dependent. However, some animals browse in addition to grasses and herbs is utilized and some domesticated animals, especially hogs, utilize mast, fungi, insects, and roots.

Range fires seldom kill all the native grasses and perennial herbs though there may be delicate relations existing among amount of grazing use, species present, and fires and season of burn. Underused range grasses may be benefited by fire or fire may help to decrease woody plant competition and heavy litter accumulation. Prescribed range burning is used as a range management tool in some areas. Hence, careful evaluation is needed to distinguish between benefits and damage. Moreover, a decision must be made as to whether the range will restock naturally, and, if not, for how long a period will it be useless for range whether or not it restocks naturally.

Table 11.--*Multipliers of expected net income from cutting unit to find present value of a cutting unit (all-age management, 5 percent discount rate)*

Portion of cutting cycle left	Years in cutting cycle						
	1	5	10	15	20	25	30
Just before cut	21.000	4.619	2.590	1.927	1.605	1.419	1.301
0.1	20.898	4.508	2.467	1.791	1.456	1.256	1.124
0.2	20.796	4.400	2.349	1.664	1.320	1.112	0.971
0.3	20.695	4.293	2.237	1.547	1.198	0.984	.839
0.4	20.594	4.190	2.131	1.438	1.086	.871	.724
0.5	20.494	4.089	2.029	1.336	0.985	.771	.626
0.6	20.394	3.990	1.933	1.242	.894	.683	.541
0.7	20.295	3.894	1.841	1.154	.811	.604	.467
0.8	20.196	3.800	1.753	1.073	.735	.535	.403
0.9	20.098	3.709	1.670	0.997	.667	.473	.348
1.0 (Immediately after cut)	20.000	3.619	1.590	.927	.605	.419	.301

EXAMPLE: Cutting cycle = 10 years; 0.4 cutting cycle remains before next cut (4 years); net value of periodic cut is $600 per acre; multiple from table (or graph) is 2.131.

Present value of cutting unit is $600 x 2.131 = $1,378.60 per acre. If the timber on the unit is completely killed and no salvage is possible because of the fire, the damage is $1,378 per acre. If salvage is possible, damage = $1,378 - net salvage value per acre.

FORMULA USED: $PV = \frac{Y}{1.0p^n} + \frac{Y}{(1.0p^r-1)\ (1.0p^n)}$

Where: PV = present capitalized value, Y = net income per acre at end of cutting cycle, r = years in cutting cycle, and n = years left in cutting cycle before next cut.

Some examples of damage and no-damage are:

1. Damage will occur if the current crop of forage is destroyed, just before its planned use.

2. Loss may occur if the fire burned in early spring so that the range had to be protected from use to prevent overgrazing.

3. Loss will occur if the fire kills desirable forage plants that will be replaced by undesirable plants.

4. No loss can be estimated unless use of the forage is planned or in progress.

5. No loss can be estimated if wildfire occurs at the time prescribed burning is planned and the results are comparable.

Damage can be estimated as the net value of the total animal month units (AMU'S) lost to use, or the cost of substitute range if the range will restock naturally. Loss of hay destroyed can be valued at market prices for hay.

Improvements and Livestock:

Loss of improvements and livestock must be considered: fences, stock pens, water installation, feeding racks, gates, and wood cattle guards. Livestock also may be injured or killed.

Losses of improvements will be evaluated at replacement cost if the range will be useful again. If the range will not be restored, either naturally or artificially, the depreciated value of improvements must be charged. Livestock will be valued at the market price of animals injured or killed, reduced by any probable salvage value.

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APPENDIX I.--RATING ESSENTIAL FEATURES OF RECREATIONAL ACTIVITY

Rating	*Criteria*[6]
1	Major deficiencies in essentials mostly not correctable. Chance for successful participation very poor. (This will seldom be used because the activity is usually impossible.)
2	Below average. Major deficiencies in essentials, mostly correctable, but expensive or difficult to correct. Success fair to good if problems are overcome.
3	Average situation. Essentials all present but minor deficiencies are present that generally can be corrected easily or ignored. Average chance of success in activity.
4	Better than average situation. Minor deficiencies keep the opportunity from being topnotch.
5	All essentials present and of good quality. Opportunity to participate successfully is exellent and proven. No deficiencies or with only minor deficiencies corrected.

Examples of Essential Features

Activity	*Essential features*
Brook trout fishing	A. Cold water stream or lake. B. Water stocked with brook trout. C. Reasonable access (implies both physical approachability as well as legal entry). D. Legal to take in season.
Swimming	A. Water (stream, lake, pond, pool, etc.) B. Water temperature 60° at least part of season. C. Secure bottom, preferably sandy. D. Preferably a gradual slope to bottom. E. Water meets sanitary standards. F. Good access.
Deer hunting	A. Large area of favorable habitat. B. Huntable population of deer. C. Access to a large territory. D. Legal to take in season. Camping or other housing facilities or sites.
Mountain climbing	A. Challenging mountain. B. Access.
Outdoor living (one aspect of camping)	A. Flat or nearly flat, well drained open spot for shelter, cooking fire, etc. B. Portable water. C. Fuel supply. D. Protection from elements (desirable). E. Access.
Cross-country hiking	A. Marked trail or path. B. Legality of passage assured. C. Possible campsites. D. Portable water at reasonable intervals. E. Pleasant environment, scenery, interesting sights, vegetation, wildlife, etc.
Birdwatching	A. Almost any place birds are found, few limitations. B. Access.

[6] *Do not consider competition from people (crowding) to be a deficiency. This is rated under "Use".*

Rating Attractions

Recreation attractions are features or conditions that support different activities or make up the environment.

The specific attractions individually provide major resources essential for fairly specific groups of activities. Thus in evaluating a site for one activity probably one attraction is rated in terms of essential features. The remaining attractions,

if any, are used to evaluate the general attractiveness of the site.

The appraiser should try to be objective in his rating. A broad viewpoint is needed comparing a situation with others occurring anywhere. The objective is to see how this opportunity compares with many other opportunities.

Categories for Rating Recreation Attractions

Outdoor environment.--This is the condition of vegetation, soil, air, water, and care that affect the senses. Consider such items as naturalness, sounds, odors, colors, purity. Where Code 1 is poorest and 5 is highest quality, the following descriptions apply.

Code 1 = Polluted, unnatural, offensive odor, noisy, too many signs, unnatural disturbances, dirty, messy, erosion, and unnatural coloration. *Code 2* = Few major, but many minor deficiencies. *Code 3* = Average of natural conditions or a state of being, acceptable level of disarray. *Code 4* = Few minor deficiences. *Code 5* = Pure; natural; sweet, clean odor; quiet or only natural sounds and noises; no signs and distractions; undisturbed; clean; orderly (natural orderliness); uneroded; and natural coloration.

Climate.--The climate of a place is the composite of the means and extremes and distribution of heat and cold, wetness and dryness, and storminess and calmness. Different climates have built-in variations, diurnal, short period, or seasonal that present expected variations within certain limits. None of these conditions is necessarily undesirable for recreation, for the recreationists must expect some risk of change and unfavorable weather. He tends to select the climate or time of year appropriate to his favorite activity. The primary consideration here is the dependableness of the typical variable weather patterns within a climate. For example, one would be disappointed to go to a normally dry area only to find it very wet, or to a normally hot area to find it cold. Thus climate may be rated 1 to 5 on the basis of the probability of drastic changes from the normal ranges. *1* = very undependable, *3* = average dependability, *5* = rarely undependable.

Wildlife and Wildlife habitat.--Consider primarily species representation, abundance, and habitat quality and diversity. *Code 1* = poor. Animal populations and habitats badly out of balance--much above or below the expected capacity of populations. Variety of species very limited, and many expected species not present. *Code 2* = below average. Generally deteriorating. Major defects in habitat or in predation, hunting, etc. Some species over capacity. *Code 3* = average. Most indigenous species present but populations below capacity in numbers. Habitat has some flaws and animal sightings may draw comment. Species representation reasonably normal. *Code 4* = above average. Situation improving and chance of desirable balance soon is very real. Many species represented. *Code 5* = most indigenous species including some that are rare or possibly endangered. Habitat supports healthy near-capacity numbers. Diverse habitat. Sightings not rare. Good balance between prey and predators.

Suggested recreation activities: (1) hunting and fishing, (2) bird and animal watching, (3) wildlife photography, and (4) biology study.

Water and watershed--this doesn't include scenic properties. Consider primarily purity, temperature, depth and/or flow; banks, shores, and bottoms, action; size of water body or stream.

Ratings must consider the amount of departure from the natural state of the water and watershed. The more nearly the water approaches the natural state the better the situation. A completely natural condition rates 5 and a much changed situation, especially if the change is ugly, polluted, or deteriorated, rates 1.

Water attractions however are often altered drastically by stream-channel straightening, and control structures, or by dams to create reservoirs or lakes. The alteration may have been made for recreation purposes, but perhaps more often recreation use is secondary to hydroelectric power, flood control, domestic water supply, or irrigation. Obviously an unnatural situation is created and must be rated as to its simulated naturalness. Thus stump and snags left in the lake are unnatural; shorelines, bottoms, and biological characteristics may be slow to assume true lake characteristics and sometimes develop

undesirable aspects. If the manmade lake or waterway has been well designed and simulates natural situations, it may become an attraction and the dam itself may be an attraction. Artificial lakes generally have very high recreational value in areas where natural lakes and or streams are not common.

Suggested activities: (1) swimming and bathing; (2) boating and canoeing; (3) sailing and motorboating; (4) water skiing; (5) sightseeing; (6) iceskating and boating; (7) photography; (8) painting and art works; (9) fishing; and (10) scuba diving.

Rating a water body can't be done the same for all activities. For example, water suited to fishing may not be suited to swimming and bathing. Canoeing waters are not necessarily good for motorboats or sailboats. Water may be too dirty for body contact recreation but suitable for boating. The purpose of the rating is important in forming the rating as an essential feature for an activity. As an attraction, however, naturalness or simulated naturalness is an important quality and no specific activity need be considered.

Geologic and topographic features.-- Every location is the product of geologic formation and change. The features may be simple and straightforward, or complex and difficult to understand. Although the interpretation of simple geology may be interesting, it is actually the unusual aspects of geology and topography that usually provide a recreation attraction. The features that deserve consideration are variety or uniqueness of display, mineralogy, formations, soil, geologic erosions of unusual character, and the interpretation of these features for the recreationists. These are features that strike the public as interesting. Although recreationists may not understand the features, they are intrigued by them and their curiosity is sparked. Interpretation may significantly increase enjoyment. Categories depend largely on the rarity of occurrence in a locality or among localities and the degree of interpretation.

1. Very common, interesting but monotonous features. Great plains, prairies, vast swamps, sand plains, mountain areas without a focus of attention. Little or no attempt made to inform the recreationist.

2. Features similar to category 1, but with some attempt to interpret for visitors.

3. Average situation, mostly humdrum but accentuated by points of interest such as rare outcrops of rock, small river gorge, abrupt breaks in the common situation such as a cliff, sudden separation from plains to mountain, waterfalls, etc. Some interpretation given.

4. Average sites with excellent interpretation.

5. Rare formations of high interest such as Yellowstone thermals, highest peaks, caves, big springs, rock sculpture from wind or water, shear cliffs of great height, dunes, canyons, glaciers, faults, good interpretation where needed.

Examples of activities: (1) rock and mineral collection, (2) photography, (3) art forms (such as painting), (4) sightseeing, (5) geology study, and (6) viewing scenery.

Biological and ecological features.-- Every area will also have certain biological and ecological features. The general vegetation situation as a macroscale feature should be included under ENVIRONMENT. Here the concern is most likely a microscale phenomenon with biological and ecological conditions as a special attraction, but emphasis is on the illustration and state of biological condition or development rather than on the beauty or amenity aspects. Consider such features as species, either because of outstanding variety or because of rare occurrence; unusual shapes or profuseness of blooms, etc., exceptional groves of trees, or concentrations of animals, state of preservation, age, number and clarity of ecological development stages; effect (good or bad) of disturbances, outliers, heritage remnants, display and arrangement, showiness or subtleness. Interpretation may add to understanding and enjoyment of lay people.

Criteria:

1. Vegetation consisting largely of pioneer stages or possibly of stagnant mature systems of ecological development

with many expected plants missing. Artificially generated vegetation. Monotony of vegetation.

2. Situation much as in 1 but with interpretation of meaning and significance.

3. Average vegetation conditions for an area with illustrations of many different biological processes and species, but so common and unspectacular that it is very commonplace. Interpretation can improve on interest value.

4. Good quality illustrations of natural development with good diversity of species, but with only modest attempt to interest recreationists with interpretation. Some features outstanding enough to attract much attention.

5. Unique examples of species or ecological states, and combining beauty of naturalness, form, development, color, bloom, and persistence. Rare species of importance or well known species of great interest.

Examples of recreation activities: (1) nature study or ecology study; (2) photography and other art forms; (3) sightseeing; (4) hiking, riding, touring; (5) collecting; (6) fruit and berry picking; and (7) natural area study and visiting.

Landscape and scenery.--In this category we are concerned with a focus of interest. Consider variety of scene, the depth of view, focus of interest, arrangement of components, detail, naturalness, and absence of unharmonious detractions.

Criteria:

1. Nearly all nearby detail, little or no depth and distance to scene. Little or no variety of components--monotonous, or with glaring detractions as inappropriate components, messiness.

2. Mostly as in category 1 but with potential for much better if given proper maintenance and development.

3. Average. Perhaps largely foreground and middle-distance views, limited variety, but variety not absent. Moderately or occasionally distracting ugliness or unharmonious components. Only moderately photogenic. Pleasant but not exciting or dramatic.

4. Mostly average but with occasionally much better views, composition, or interest.

5. Full range of depth and variety. Usually has a focus of interest, though this may encompass the total view. Dramatic, photogenic, well arranged components. Or it may be a scene of limited depth but impressive detail, arrangement of variety on a small scale.

Suggested recreation activities: (1) sightseeing; (2) touring, hiking, riding; (3) photography; (4) relaxation; (5) escape; (6) outdoor living; (7) painting (drawing); and (8) scenic drives.

Historic or heritage features.--Historic features are not readily identified on the ground by casual inspection of the site. Historic significance of a site comes about because some event of historic significance took place there. It is a part of our heritage and we must be told that it happened here. It may be a tree under which an Indian Treaty was signed, a building where an important person was born, a battlefield, a place where an important discovery was made, a "first" building.

Significance of the site is more a matter of the significance of an event or person. Events of National or international significance would rank highest; those of strictly local interest and importance lower. Many times historic significance can be developed by research into the history of a place. Most areas have some historic interest feature if they are developed.

The age of the historic event is also a criteria. However, age is apt to be correlated with importance for minor historic events tend to lose interest with time. Important events will hold interest for longer spans. Historic events having to do with beginnings, firsts, one of kind, important changes, or great discoveries may be of great significance. Often if the sites are of great significance, they are now National parks, State parks, or are registered historic places.

The more nearly the site still represents the conditions at the time the event took place the more important the site. Thus some sites of historic importance are useful because they show some past commonplace situation illustrating life style or state of culture. A high

rating is given to a site that has been preserved in much of its original state.

Suggested activities: (1) sightseeing, (2) history study, (3) photography and art forms, (4) recreation of primitive times, (5) ecological study, and (6) hunting for evidence of historic interest.

Anthropological and prehistoric features.--Prehistoric sites are "discovered" and subsequently developed or studied to deduce the significance of the find. Discoveries that become important in tracing the past activities and development of man have considerable importance and consequently interest. Much depends upon the manner and effectiveness of display and interpretation given so that recreationists can understand what they see. The rating should be in terms of the significance and interest in the "find" as well as how it is displayed. "Finds" are not related to specific events or people but rather to the evidence of a culture or stage in the progression of man through the past.

Suggested activities: (1) sightseeing; (2) anthropological study; (3) revelation of man's origins; and (4) exploration and hunting for relics, artifacts, or other evidence. (On known sites, this should be controlled.)

Occupancy.--Occupancy per se by permanent or semipermanent residents is not important. What is of importance, however, is how such occupancy relates to the activities being rated. Thus to find someone living in a wilderness would be inappropriate; it would be equally so to find no residents in a good agricultural area. The critical considerations relate to the appropriateness of the occupancy and somewhat to its density in relation to the activity in question. In general, if interruptions by occupancy impair an activity it is undesirable; if the interruptions do not influence the activity or even improve the opportunity, it is desirable.

Improvements.--Improvements generally have the purpose of increasing capacity, managing people, providing safety and access, or serving needs for essential services. Because the improvements intrude on the site, they should be functional but unobtrusive. They should usually not be a focal point. Thus the appropriateness of the type, design, materials, location, and effectiveness of performing functions are the criteria for rating. Exceptions might be improvements or structures that are themselves the major attraction--for examples, the St. Louis Gateway Arch, a museum, or a lodge.

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ACKNOWLEDGMENTS

Fire effects involve a complex of biological, economic, and management relations. There are diverse opinions on many issues while the core problems have seldom been systematically attacked during the three-quarters century of fire control in the United States. This report is a synthesis of information and ideas from sources too numerous to be cataloged individually although significant ones are referenced in the text.

Some more specific assistance was obtained by Cooperative Aid studies with universities. Among these was an Economic Analysis of Fire Damages made by Larry Streeby while a Doctoral candidate at the University of Wisconsin, under the supervision of Dr. William R. Bentley. Although no formal publication of results has been made to date, Streeby's work has provided the principle economic concept used in this report. Professor Carl Settergren of the University of Missouri studied the effects of fire on watersheds. His Doctoral thesis (University of Colorado) was a fine review of present and past knowledge and problems, highlighting the very complex and difficult nature of this aspect of damage appraisal. Master's candidate Norman H. Fennell, under the supervision of Dr. Russell J. Hutnik, The Pennsylvania State University, provided insight into the ecological effects of fires on eastern hardwood stands.

Robert M. Loomis was associated with the project throughout its life, concentrating on the effects of fires on eastern hardwoods. His work has provided important guidelines for appraising the often puzzling results of the typical moderate intensity fires occurring on these fire-prone and extensive woodlands.

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Crosby, John S.
1977. A guide to the appraisal of wildfire damages, benefits, and resource values protected. USDA For. Serv. Res. Pap. NC-142, 43 p., illus. North Cent. For. Exp. Stn., St. Paul, Minnesota.

A set of value concepts and methods for appraising both values-at-risk and changes in value resulting from wildfire are presented. Emphasis is placed on the effects of forest fires in terms of their affects on human and organizational goal achievement. Fire effects that help achieve goals are beneficial; those that hinder goal achievement are undesirable and create damage.

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Status, distribution, and movements of MARTENS in Northeastern Minnesota

L. DAVID MECH AND LYNN L. ROGERS

NORTH CENTRAL FOREST EXPERIMENT STATION
FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

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STATUS, DISTRIBUTION, AND MOVEMENTS OF MARTENS IN NORTHEASTERN MINNESOTA

L. David Mech and Lynn L. Rogers

The Eastern pine marten (*Martes americana americana*) formerly was found throughout the coniferous portions of the Great Lakes Region and New England northward to the tree line in Manitoba, Ontario, and Quebec (Hall and Kelson 1959). Today, the range of that subspecies in the United States is restricted to small areas of Maine, New York, and Minnesota. The Sierra Club recently petitioned the U.S. Department of the Interior to list the Eastern pine marten as an endangered species (Anonymous 1976). The consequent need for information prompted us to review the status, distribution, and habits of this subspecies in Minnesota.

THE STUDY AREA

Data concerning the distribution of the Eastern pine marten were obtained throughout northeastern Minnesota, much of which is composed of the Superior National Forest, including the Boundary Waters Canoe Area (BWCA). Studies of movements were conducted in a portion of the Superior National Forest centered 24 km southeast of Ely in the west-central part of the larger study area (fig. 1).

Northeastern Minnesota is in the transitional zone between boreal and deciduous forests (Maycock and Curtis 1960), and 18 percent of the Superior National Forest (almost all of it within the BWCA) is still virgin (Heinselman 1973). Disturbed areas support primarily trembling aspen (*Populus tremuloides*) and white birch (*Betula papyrifera*) communities. Vegetation of virgin communities within the BWCA was studied in detail by Ohmann and Ream (1971). Geology, soil, topography, and weather of the study area

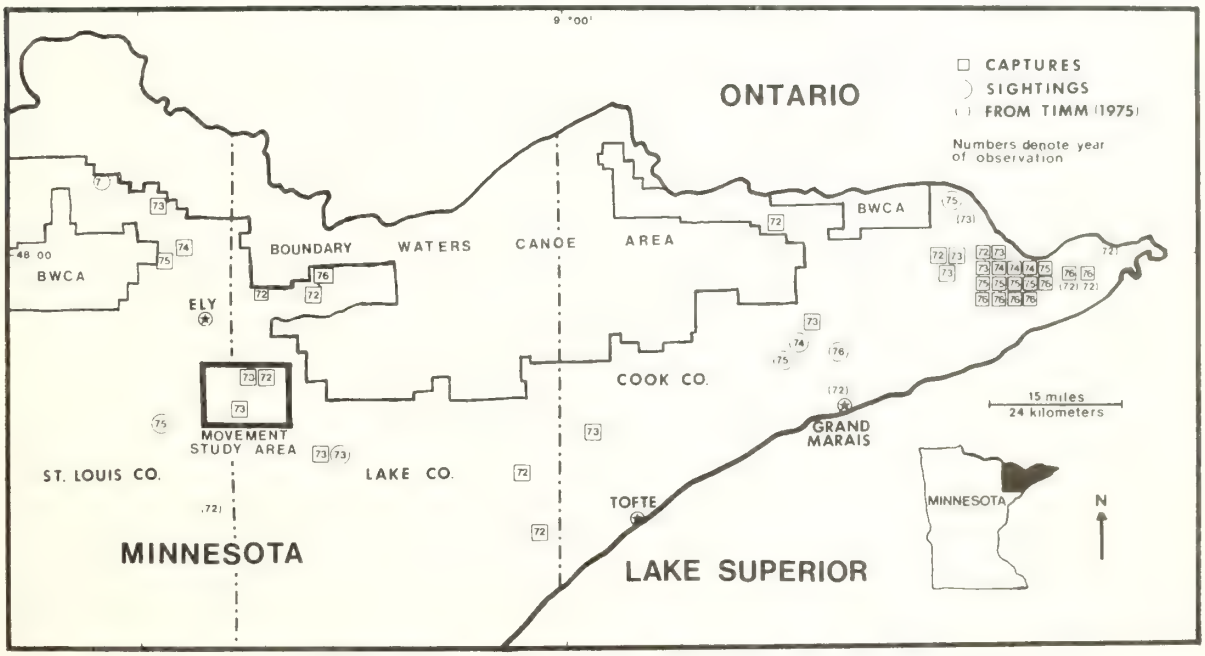

Figure 1.--*Records of Eastern pine martens in Minnesota, 1972-1976. (Not shown is a marten captured in winter 1974-75 in T70N, R23W, Section 11, near International Falls, Koochiching County, Minnesota.)*

was described by Stenlund (1955b) and Mech and Frenzel (1971). The study area is relatively flat, with elevations ranging from 184 to 701 m.

METHODS

Data on the status and distribution of martens in Minnesota were obtained from many sources. Of greatest value were confiscation records of the Minnesota Department of Natural Resources, based on martens trapped accidentally and reported to conservation officers. We also interviewed several long-time trappers, obtained fur records for adjacent Ontario from "Statistics Canada", and recorded marten observations from various field workers.

Information on marten movements was obtained by radio-tracking. Martens were accidentally live-trapped in wire box traps set for snowshoe hares (*Lepus americanus*) and fishers, (*Martes pennanti*), and one was donated by a trapper whose mink (*Mustela vison*) trap held the marten harmlessly around the neck. Two martens were captured in wolf (*Canis lupus*) traps.

Martens to be radio-tagged were first anesthetized with a combination of phencyclidine hydrochloride and promazine hydrochloride administered intramuscularly according to dosages recommended by Seal *et al.* (1970). Usually one-half concentration booster doses had to be administered to hold an animal out for 20 to 40 minutes.

Radio-collars (Mech 1974) and ear-tags were applied to the martens, and the animals were released where caught. Radio-tracking was primarily by air (Mech 1974), with some supplementary ground tracking. Hoskinson (1976) used aerial radio tracking in the same areas and found that location errors varied from 7 to 76 m. A few examinations were made of marten resting sites, with the observer "homing-in" on the animal on foot. Home-range estimates were based on the minimum area method (Mohr 1947).

HISTORY OF MARTENS IN MINNESOTA BEFORE 1970

The former abundance and eventual reduction of the pine marten in northern Minnesota are documented in the records of fur buyers. Three to 271 marten pelts were purchased each year from 1801-1808 at Henry's Post on the Red River, and approximately 1,000 pelts were purchased by a fur trader on Lake Superior in 1856 (Swanson 1940). In 1857, approximately 1,600 marten pelts were collected from 5 posts in Minnesota (Schorger 1942). The Joseph Ullmann Company purchased 43 marten skins from H. Miller of Lake Superior City (*sic*) in 1863 and bought 96 skins in Crow Wing County in 1871.

A decline in pine martens became evident in the late 1800's (Swanson 1940). The Joseph Ullmann Company purchased less than 100 marten pelts in Minnesota between 1872 and 1890. Nevertheless, martens continued to persist in a few areas. Three trappers took 43 martens from the vicinity of Caldwell Brook in Koochiching County between December 1894 and May 1895 (Swanson *et al.* 1945), and 2 trappers from Beltrami County took 22 martens in 1897 (Swanson 1940). However, even these pockets were decimated by the early 1900's (Johnson 1922, Swanson 1940, Timm 1975). The last marten recorded in Beltrami County was taken in 1918 (Schorger 1942), and the last one captured in northwestern Minnesota was taken in the Northwest Angle in 1920 (Swanson *et al.* 1945).

The decline of the pine marten occurred during the settlement of northern Minnesota. Trapping pressure undoubtedly had increased, and during the late 1800's and early 1900's much of northern Minnesota was logged (Dana *et al.* 1960). Most of what was logged was burned, and even the virgin forests of northeastern Minnesota experienced twice as many fires from 1868 to 1910 as they had before 1868 (exceptionally large areas burned in 1863, 1864, and 1894) (Heinselman 1973). Consequently, the mature coniferous habitat preferred by the pine marten (see below) was greatly reduced during the late 1800's and early 1900's. Yeager (1950) concluded that logging is the single most destructive factor to marten populations.

Evidence of pine martens in Minnesota after 1920 is restricted to the northeastern corner of the State. In winter 1928-1929, Mike West (personal communication, 1976) an experienced trapper, found several sets of marten tracks in Cook County between Mountain and Moose Lakes near the Canadian border. Art Allen, a game warden, also found tracks near Cherokee Lake in Cook County in 1938 (handwritten report in files of the Minnesota Department

of Natural Resources). Moreover, lumberjacks of the Consolidated Paper Company accidently captured several pine martens in weasel (*Mustela* spp.) traps in the vicinity of Chester Lake in Cook County in the mid 1930's (Mike West, personal communication, 1976). The Chester Lake location had been made accessible only shortly before by a newly constructed logging road. The two other areas mentioned above were virgin conifer stands according to maps published by Heinselman (1973) and Marschner (1930).

Martens have been completely protected in Minnesota since 1933. However, the species has a low biotic potential (Marshall 1942), which may partly explain the population's low rate of increase. Nevertheless, it appears that a more important factor may have been the scarcity of preferred habitat with its associated prey species. The forests have been largely protected from fire since the early 1900's (Heinselman 1973), and fire protection generally results in an increase in shade-tolerant conifers, particularly balsam fir (*Abies balsamea*) and spruce (*Picea* spp.). Such protection from fire may have led to an improvement of marten habitat and an increase in associated prey species in northeastern Minnesota. Currently, most of the stands of aspen (*Populus* spp.) and paper birch that arose following fires in the early 1900's are being succeeded by spruce and fir.

Marten numbers apparently began increasing in Minnesota during the 1950's and 1960's. Between 1953 and 1963, four martens were trapped in northern St. Louis, Lake, and Cook Counties in the Superior National Forest (Stenlund 1955a, Gunderson 1965). A fifth specimen was captured in Lake County in 1969 (Maxham 1970).

RECORDS OF MARTENS IN MINNESOTA, 1970-1976

The marten population of northeastern Minnesota increased markedly in the early 1970's as evidenced by the fact that 50 martens were captured or sighted during that period (fig. 1): 33 in Cook County, 9 in Lake County, 5 in St. Louis County, and 1 in Koochiching County. Thirteen of the martens were observed in 1972, 12 in 1973, 5 in 1974, 10 in 1975, and 10 in the first 9 months of 1976.

We attribute the lack of marten records from the BWCA to the fact that the area is largely inaccessable during the trapping season rather than to a paucity of martens. In fact, we consider the BWCA with its dense, virgin stands of conifers as a probable reservoir for martens. Locations where marten tracks were found in 1928-29 and in 1938 (see above) were both in the BWCA, suggesting that at least some of the populations from which the recent expansion arose may exist in the BWCA.

An increase in martens similar to that in Minnesota apparently occurred in Ontario[1].

Period	*Average number per year*	*Average value per pelt*
1920-1930	4,691	$22.31
1931-1940	[2]1,425	15.64
1941-1950	1,431	28.31
1951-1960	3,670	8.58
1961-1970	17,164	6.14
1971-1975	23,882	9.28

The increase in production of marten pelts in Ontario occurred despite a drop in fur prices and despite only slight increases in the number of registered trap lines (M. Novak, personal communication, 1976). The vegetation history of Ontario adjacent to Minnesota is similar to that of Minnesota, and it seems possible that the increase in both Ontario and Minnesota were due to the same factor(s). Further evidence that similar factors affected both Ontario and Minnesota marten populations is that martens in both areas declined when the areas were logged.

RESULTS OF EXAMINATIONS OF CAPTURED MARTENS

Captured specimens included 6 males, 3 females, and 32 of undetermined sex. The carcasses of two males and a female were examined by the Bell Museum of Natural History, University of Minnesota (ECB No. 2328, 2329, and 2330). The female had light, even toothwear and a bulge in each

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[1] *From records of "Statistics Canada", Ottawa, Ontario.*

[2] *Extensive areas within Ontario's major marten range were logged in the 1920's and 1930's.*

uterine horn, indicating the presence of two blastocysts, an early stage in pregnancy (Marshall 1942). One of the males had light to moderate toothwear but appeared to be nonbreeding in November 1973 when killed. The other male's baculum was not fully developed, indicating that the animal was a young-of-the-year.

HOME RANGES AND MOVEMENTS

Three males and one female martens were radio-tracked intermittently during periods of 28 to 100 days (table 1). A total of 64 marten-days of locations were obtained. Male No. 2145 was captured three times.

All four appeared to have established home ranges. Home ranges of the males extended over 10.5, 16.6, 19.9 km^2 and that of the female, 4.3 km^2 (fig. 2). If we had recorded more locations for each animal over a longer period, they might have shown larger home ranges.

Nevertheless, these home-range sizes are larger than those found by Hawley and Newby (1957) for martens in Montana based on the capture-recapture technique. But they are smaller than the ranges found by Marshall (1951) in Idaho based on the snow-tracking of individuals.

The home ranges of male Martens 2101 and 2145 overlapped considerably (fig. 2). However, these individuals were studied during different periods (table 1), so we do not know whether they occupied their ranges simultaneously. Furthermore, the areas where each marten was found most were where the other was found least. Thus, some kind of spatio-temporal aversion could have existed between the two if they were contemporaries. Hawley and Newby (1957) noted that all of their study animals of the same sex, except for two males, had separate home ranges.

In 14 cases, consecutive daily locations were obtained for the males. On three of these occasions the marten was found in the same location on consecutive days. Excluding these days, the straight-line distance between the pairs of locations averaged 1.8 km with a range of 0 to 3.8 km.

Marten No.	*Dates*	*Distances in km*
2101	February 24-25, 1972	1.7
	25-26	2.9
	26-27	1.8
	27-28	0.0
	28-29	0.6
	March 3-4	1.5
	4-5	2.0
	April 4-5	0.4
	April 24-25	3.8
2145	February 5-6	2.8
	6-7	1.6
	March 15-16	0.0
2808	June 12-13	0.0
	13-14	0.4

These minimum daily distances our martens traveled were more than those of Hawley and Newby (1957). Marshall (1951) tracked some martens much farther in a day, but the straight-line distances between daily locations were similar to ours.

On 13 occasions, martens were located from the ground in their resting sites, which in 12 cases were in ground burrows, rock piles, or rock crevices (table 2). Once Marten No. 2101 was discovered 6 m up in a jackpine lying and sitting (much like a squirrel) quietly on a branch as the observer circled the tree below. The only other descriptions we have found of

Table 1.--*Background information about martens captured*

Marten No.	Sex	Weight: gm	Date caught	Date of last location	Total locations	Home range size km^2
2101	M	775	January 21, 1972			
2101 (recaptured)		[1]929	February 16, 1972	May 2, 1972	26	16.6
2139	F	672	December 14, 1972	January 11, 1973	10	4.3
2145	M	818	January 24, 1973			
2145 (recaptured)		680	February 12, 1973			
2145 (recaptured)		705	February 15, 1973	March 26, 1973	18	19.9
2149	M	937	February, 19, 1973	not radioed		
2808	M	1,012	February 27, 1973[2]	June 20, 1973	11	10.5

[1]Weight on February 22, 1972 after being kept in captivity since February 16, 1972.
[2]Held captive for other studies until April 20, 1973 when it was released where caught.

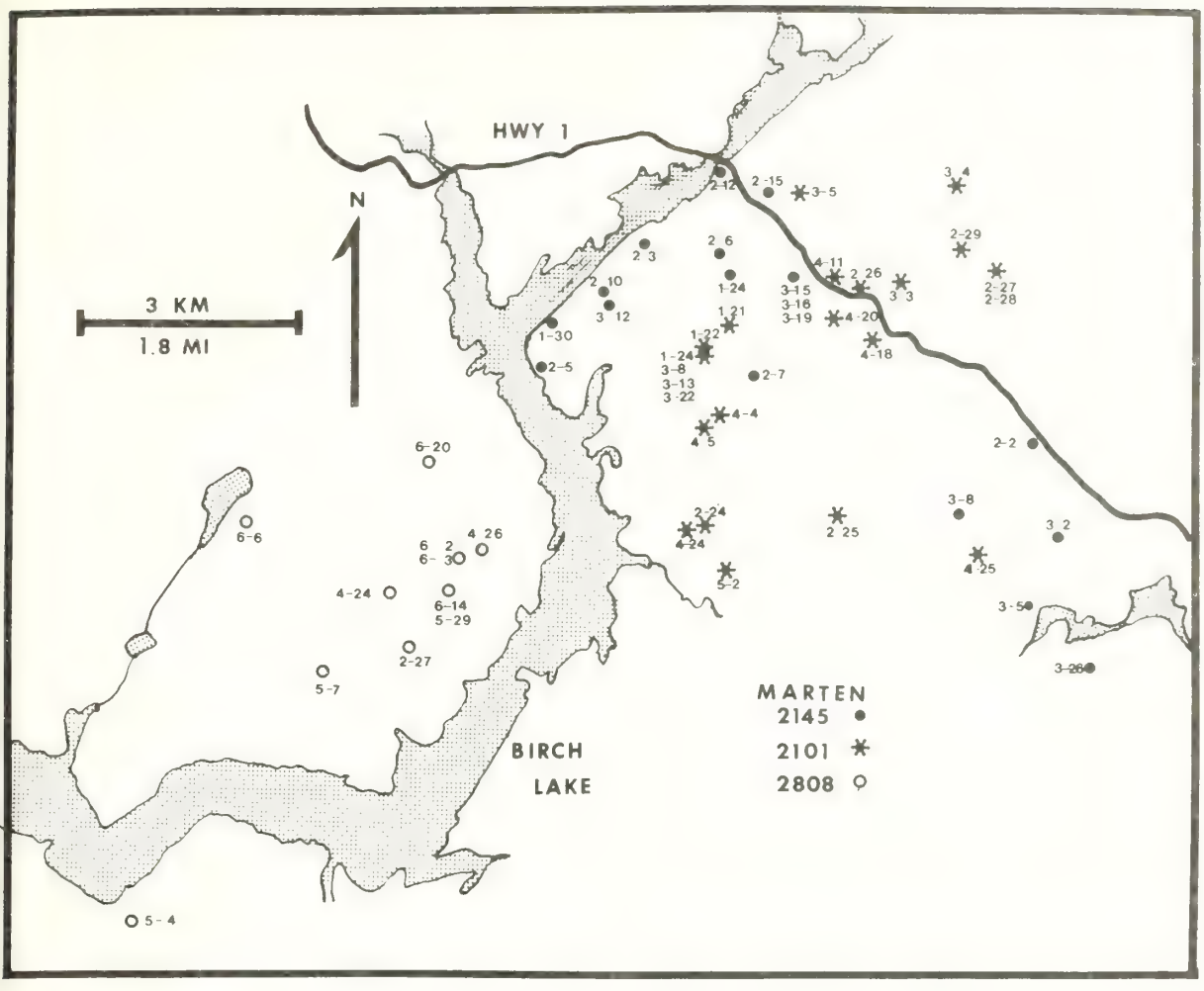

Figure 2.--*Locations of three radio-tagged martens in northeastern Minnesota (see fig. 1 and table 2). Numerals at each location represent dates.*

Table 2.--*Resting sites of radioed martens*

Marten No.	Date	Type of site	Habitat
2101	January 22, 1972	Burrow or crevice under boulder	Black spruce, birch, poplar
	January 24, 1972[1]	Burrow or crevice under boulder	Black spruce, birch, poplar
	April 4, 1972	Rock crevice	Black spruce
	April 5, 1972	Rock pile	Black spruce
	April 11, 1972	Burrow	Red pine, aspen, birch
	April 18, 1972	Burrow or crevice	Black spruce, aspen
	April 20, 1972	Burrow under log	Red pine, aspen, birch
	April 24, 1972	Burrow under rock	Jackpine, spruce, aspen
	April 25, 1972	Burrow under rock	Jackpine, aspen
	May 2, 1972	6 meters up in Jackpine	Jackpine, black spruce
2139	December 28, 1972	Burrow or crevice	Balsam
	January 5, 1973	Burrow or crevice	Open birch, aspen
	January 9, 1973	Burrow or crevice	Aspen, birch

[1]Different den but within 100 m of January 22 location.

marten resting sites were those of Marshall (1951) who reported that of 16 martens tracked to dens, 13 used hollow logs and 3 used hollow stumps.

The distributions of locations for each of the martens was uneven, with some areas being used much more frequently than others. Because aerial determination of locations is subject to error (Hoskinson 1976) we cannot say for sure that exactly the same locations were used more than once, but certainly Marten 2101, for example, made multiple visits to relatively small areas (fig. 2), as was also found by Hawley and Newby (1957) and Marshall (1951). In the case reported by Marshall (1951) a marten repeatedly returned to an elk (*Cervus elaphus*) carcass to feed.

A gross examination of cover types in the marten home ranges indicates that the animals ranged through a variety of vegetation. Generally the areas inhabited by the radioed martens were similar to much of the rest of the forest, which was logged and/or burned primarily between 1890 and 1920 (Stenlund 1955b).

Examination of the specific daytime resting sites of the radioed martens also indicates that they used a variety of forest cover types. About the only generalization that can be drawn from the data is that most of the resting sites were situated in stands of conifers, many of which included some white birch and/or aspen (table 2). A high percentage of the marten captures and sightings were also in conifer-dominated areas or mixed stands (fig. 1 and Marschner 1930).

Marshall (1942) concluded that martens are adaptable in their use of cover types. He found martens primarily in conifer stands, but apparently there were few stands of deciduous trees in his study area (Marshall 1951). In Ontario, DeVos (1952) stressed the marten's need for mature timber, disagreed that conifer cover makes the best habitat, and stated that mixed stands appear best. However, DeVos *et al.* (1959) later reported excellent evidence that areas of mature conifers produced greater numbers of martens than did interspersed areas having fewer mature conifers. Further, Koehler *et al.* (1975) studied martens in coniferous forests in Idaho and found that they preferred stands with canopy cover greater than 30 percent.

Although martens are known to be good swimmers (DeVos 1952), we have found no records of distances over which they can swim. Thus, it is interesting to note that male Marten 2808 swam across Birch Lake twice between May 7 and May 29, 1973 (fig. 2). He could have crossed at a point only 30 m wide, just east of his known range, but if he took the most direct route between his locations on each side of the lake, he would have had to swim at least 64 m.

FUTURE OUTLOOK

If the present increase in martens in northeastern Minnesota and the apparent increase in adjacent Ontario are indeed due to maturing forests and increases in shade-tolerant conifers, marten numbers should continue to rise for some time to come. It currently is uneconomical to harvest much of the aspen-birch-fir timber that abounds in the Superior National Forest because the stands are located so far from the mills that transportation costs make cutting of such stands unprofitable. If the virgin forests of the BWCA indeed serve as reservoirs for the marten, the no-cut policies that continue in effect in the Interior Zone of the BWCA further enhance the future of the marten in Minnesota. Martens are protected in Minnesota and are taken only accidentally in traps set for other species. They apparently are increasing despite this level of exploitation. However, martens are very easily trapped, and their numbers can easily be decimated by overtrapping (Yeager 1950, DeVos 1952, DeVos *et al.* 1959). Therefore, no legalized trapping is recommended. Studies should be conducted to determine the extent to which the relatively inaccessable virgin conifer stands of the BWCA actually serve as a reservoir for martens in northeastern Minnesota.

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Mech, L. David, and Lynn L. Rogers.
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OXFORD: 156.2:149.74. KEY WORDS: sable, telemetry, trapping, habitat, home range.

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SECONDARY WOOD RESIDUE: Production, Use, and Potential In The TWIN CITY Area

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SECONDARY WOOD RESIDUE: PRODUCTION, USE, AND POTENTIAL IN THE TWIN CITY AREA

Eugene M. Carpenter, *Market Analyst*
Duluth, Minnesota

Manufacturing wood products from lumber, lywood, and particleboard inevitably produces awdust, shavings, and trim. Much of this waste naterial is discarded, and little has been done to nvestigate potential salvage opportunities. Salvage f this waste material could augment the supply of ood fiber, alleviate the environmental impact and educe the cost of solid waste disposal, and help vercome the energy crisis.

To get a better understanding of the wood waste roblem and the salvage potential we set out to nvestigate the amounts and kinds of wood residue eveloped by secondary wood product manufacturers n a selected metropolitan manufacturing area, to etermine what disposal was made of the material, nd to identify physical characteristics, location, osts, and potential markets.

STUDY METHODS

The Area

The study encompassed the Minneapolis-St. Paul netropolitan area, and included the Counties of Anoka, Dakota, Hennepin, Ramsey, and Washington (fig. 1). Although this area is approxinately 50 miles wide by 60 miles long, the bulk of he residue produced is within a 20-by-30-mile area n Hennepin, Ramsey, Washington, and northern Dakota Counties.

Data Collection

Data from firms generating less than 1 ton of ood residue per week were collected by telephone. Information was requested on volume by species and kind of residue, moisture content, contamination, methods of disposal with resulting income and/or costs incurred, and anticipated changes in any of these factors in the near future. Firms producing a ton or more of wood residues a week were visited in person. At that time samples of the coarse and fine residues were obtained where possible. Fine residue is sawdust, shavings, sander dust, and router chips; coarse residue is the solid trim from lumber, plywood, and particleboard.

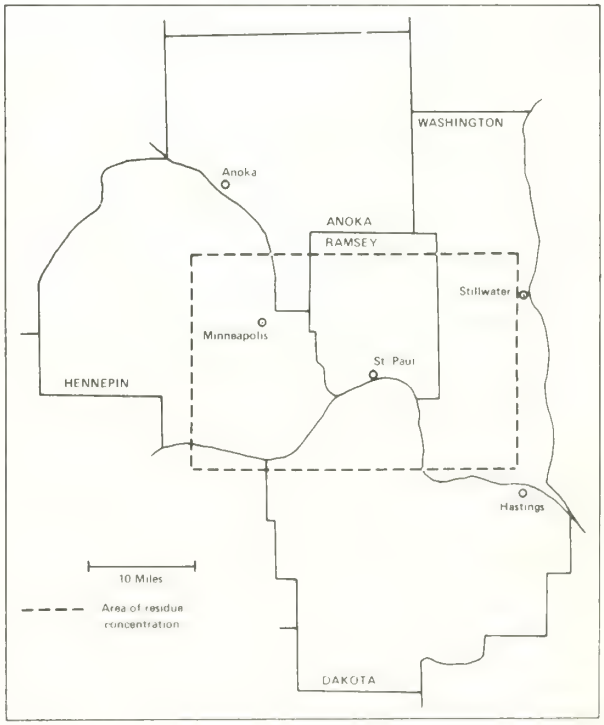

Figure 1–*Map of Minneapolis-St. Paul, the Study Area.*

Residue estimates were collected from 91 firms in selected Standard Industrial Classes (SIC) that are considered secondary wood product manufacturers:

Product Description	*SIC*	*Number of Plants*
Hardwood dimension and flooring	2426	6
Millwork and related products	243	54
Wood containers and pallets	244	9
Miscellaneous wood products	249	5
Furniture	251	3
Fixtures	254	14
		91

The samples of fine residue were evaluated by placing the material in a drum with a perforated, weighted, floating lid. The drum was dropped and shaken to simulate the compaction that might be achieved by treading the material while loading a truck. One cubic foot of the compacted material was weighed, placed in a moistureproof bag, and taken to the laboratory for screen analysis and moisture content determination. The fine residues were screened through a Williams Standard Pulp Testing Apparatus with six 24-inch square trays. After being shaken for 5 minutes the trays were weighed, then shaken for another minute, and reweighed. Only minor changes were recorded from the additional shaking. Sieve sizes were 1 inch, 1/2 inch, 1/4 inch, 1/8 inch, 1/16 inch, 1/32 inch, and dustpan.

An estimate was made of the size of the coarse residue pieces, and samples were bagged for moisture content determination. Moisture contents are reported on a green basis for both fine and coarse residues.

AMOUNTS AND KINDS OF RESIDUE

About 32,000 tons of residue were generated in 1974 by all secondary wood product manufacturers in the study area. Of this, 10,295 tons were used for fuel, 10,101 tons were dumped or given away, and 11,836 tons were sold.

Five millwork firms burned their residue for plant or process heat and hence did not estimate amount generated. All indicated that none of their residue would be available for another use. We estimated that these firms generated about 9,500 tons annually, but these data are not included in the following analysis.

Fine Residue

Forty-two firms generated 12,785 tons of fine residues annually. These fine residues were kept separate from other residues and trash. Twenty of the 42 firms produced 50 tons or more annually and accounted for 98 percent of the total amount of fine residue produced.

We classified the fine material as hardwood or softwood based on botanical origin, that is, from broadleafed trees or conifers, and not on the density of the wood, and as shavings, sawdust, or a mixture of the two.

Of the 12,785 tons of fine residue, 80 percent is hardwood sawdust or shavings, nearly all mixed together by 16 firms. Two firms have small amounts of hardwood shavings, and three firms have small amounts of hardwood sawdust. The remaining 2 percent is a conglomerate of hardwood and softwood sawdust and shavings mixed together, produced by 19 firms.

The weight of mixed shavings and sawdust ranged from 6.0 to 17.5 pounds per cubic foot as collected and 5.4 to 16.2 pounds per cubic foot ovendry (table 1). Sawdust ranged from 14.1 to 15.4 pounds green, and 8.8 to 14.0 pounds ovendry. Green shavings weights were 4.5 to 16.6 pounds, ovendry were 3.8 to 7.9 pounds.

About two-thirds of the fine residue had moisture content of 10 percent or less, and 2

Table 1.—*Average weight and size characteristics for fine residue samples*

Kind of material	Samples	Weight per cubic foot		Size of material[1]	
		Green	Dry	<1/8 inch	1/8 inch+
	Number	*Pounds*		*Percent*	
Sawdust and shavings	12	12.1	10.5	68	32
Sawdust	3	14.7	10.0	99	1
Shavings	2	10.5	5.8	17	83

[1]Sample percents were weighted by annual volume to deriv the table value.

rcent was from 10 to 25 percent. Only 13 percent d a moisture content between 40 and 55 percent, een basis. The wettest material came from wood ntainer and pallet firms.

Nearly all the mixed samples, passed through the 2-inch screen, and none had as much as 1 percent material 1 inch or larger. Less than 2 percent of e shavings samples stayed on the 1-inch screen.

Contamination was not a problem in the fine sidues.

Coarse Residue

Seventy-one firms generated 9,947 tons of coarse ood residues in 1974. Twenty-eight of these firms oduced more than 50 tons annually; the top five elded slightly more than half the total amount. ixtures of fine and coarse residues were classed as arse. Only small amounts of fines were included these mixtures. Most of the coarse residue is her hardwood lumber trim or a mixture of mber, plywood and/or particleboard (table 2). A all amount of hardboard is included in the mixed tegories.

Trimmed blocks, strips, and edgings of lumber, ywood, and particleboard from 1/2- by 1/2- to 4- 6-inch widths in lengths of 1/2 inch to 16 feet ere discarded. The wider lumber waste is nerally less than 3 feet long with 6 to 10 inches mmon. Most of the longer material is less than 8 et long, mostly thin strips. Occasional pieces of ywood or particleboard were found with surface

able 2.—*Distribution of coarse residue by species and kind of material*

Kind of material	Number of firms	Tons	Percent
Lumber--Hardwood	13	4417	44
Lumber--Hardwood and softwood mixed	3	1341	13
Plywood--Hardwood and softwood mixed	1	17	([1])
Particleboard--Hardwood and softwood mixed	2	142	1
Mixed solid[2]--Hardwood and softwood mixed	27	3282	33
All mixed[3]--Hardwood and softwood mixed	25	748	8

[1]Insignificant amount.
[2]Mixture of lumber, plywood, and/or particleboard.
[3]Includes both fine and coarse residues.

areas up to 200 square inches; they were in every imaginable configuration.

More than 70 percent of the coarse residue had a moisture content less than 15 percent; a small amount was in the 20-percent range, and about one-quarter was in the 50-percent range.

Contamination was minor for coarse residue. The firms who mixed their residue with other trash said foreign materials could easily be kept separate if markets were found for the wood portion. Occasionally paint or other finishes were found, but the most serious contaminants were vinyl overlays or high density laminates. However, these were extremely rare.

DISPOSAL

Fine Residues

Most of the fine residues were used. Eleven firms reported dumping the material, but they accounted for less than 1 percent of the total volume. Four percent of the total was used for plant fuel by two firms.

Seventy-six percent of the fines were sold and 19 percent were given away, mostly for animal or poultry bedding. At least four sawdust and shavings dealers operate in the study area, but several firms dealt directly with local farmers.

The market was generally unorganized. Price was negotiated on an individual basis, and depended somewhat on dryness, volume, and loading facilities. Prices reported ranged from $0.22 to $2.86 a cubic yard, with $0.75 an approximate average. Those firms giving away their fine residues seemed satisfied to have the material removed regularly at no cost.

Coarse Residues

Disposal of coarse residues was generally a problem. Sixty-three percent was dumped or burned as waste by 62 firms. Most firms contracted to have material hauled away; a few used their own trucks. Thirteen percent was given away for fire wood or youth group woodworking projects. Two percent was used for plant or process heat by three firms, and 22

percent was sold to charcoal manufacturing plants by two firms.

Annual disposal costs reported ranged from zero to $9,000, with a dozen firms indicating annual expenses of more than $1,000. Costs averaged about $2.25 per cubic yard. Many of these firms had investigated alternative disposal methods including chipping and fuel. However, investment requirements were too high to justify installing necessary processing equipment for the amount of residue generated.

Although almost all firms would welcome an alternative to dumping the residue, surprisingly few considered disposal to be a big problem. Many firms that paid several hundred dollars per year for disposal probably did not consider this an exorbitant amount relative to their costs of doing business.

TRENDS

Most of the 91 firms interviewed indicated they did not expect any significant change over the next 3 years in the amount or kind of residue produced. Three firms had definite expansion plans and estimated a doubling of residue production. A few firms commented that their business activity was slightly depressed and they would expect moderate increases only if the economy improved. A few others expressed the contrary view that business was good during the study period. Thus, there was no consensus to suggest residue volumes were adversely influenced by the state of the economy for the groups studied.

None of the firms expected to substitute other materials for the wood components in their products or processes. Also, none indicated they planned to change the methods they were using. For example, none planned to increase the use of cut-to-size or prefinished parts, which might shift residue accumulation outside the study area.

POTENTIAL USES

Fiber Potential

The current extensive use of the fine wood residues for animal and poultry bedding will continue. And, although the market in the study area is presently somewhat unstructured, demand is strong and will compete with any attempt to divert material to other uses.

Minnesota's status as a leading producer of turkeys creates a market for 5 to 6 million cubic feet of loose litter annually. In addition, the broiler chicken industry requires about a million cubic feet. Bark-free, dry shavings are preferred for this use. An attempt by a local processing firm to convert coarse lumber trim to shavings for animal bedding was unsuccessful.

Specialty markets for pet and laboratory animal bedding exist. These products command relatively high prices, but require special processing, including sterilization.

The manufacture of wood flour from dry wood residue is described by Reineke (1966). Primary uses are in the manufacture of linoleum, explosives, and plastics. Total consumption is not large, and consumer requirements are rather exacting.

The manufacture of floor sweeping compounds from dry sawdust is usually a sideline for firms engaged in other wood processing activity or by small specialty firms with local or regional distribution (USDA 1966).

The coarse material has poor potential for use as a pulp furnish because of the low moisture content, mixture of species, and the problem of developing a suitable pulp chip from the conglomerate of trim. One exception might be as a furnish for the less particular roofing-felt market. Some of the fine material has been used for this product.

Both fine and coarse residue can be used for particleboard manufacture because dry material is usually preferred. However, no local market exists, and the supply is too limited to support an efficient particleboard mill. Transportation costs prevent the shipment of all but the highest quality dry shavings to regional particleboard markets.

Charcoal manufacture offers a potential market for the half of the coarse residue that is hardwood. However, charcoal producers are located outside the study area and transportation costs are probably prohibitive for most accumulations.

Fuel Potential

The use of secondary plant wood residues for fuel ffers a real potential because of the low moisture ontent of the material. There are several types of urning systems available, many requiring a homo- eneous furnish with particles less than 1/8 inch in ze. Thus, the fine residues would need only minor rocessing. The coarse residues would need chipping r coarse hammermilling in addition to further eduction in a fine hammermill. Fluidized bed boilers re available to burn unprocessed coarse material, lthough processing increases efficiency.

An average of 8,500 Btu's per pound is a commonly sed "higher heating" value for ovendry wood. sing this base, and adjusting for average as-fired oisture content, it is estimated there are approxi- ately 309 billion Btu's potentially available from ie wood residue in the study area, excluding the mount now being burned for plant fuel.

Fuel Comparisons

Assuming that No. 6 fuel oil produces 150,000 tu's per gallon, costs 32¢ per gallon, and has an 80 ercent combustion efficiency, the cost of fuel to roduce steam would be $2.67 per million Btu's. To qual this cost burning wood as a fuel, the producer ould afford to pay as much as $13.60 per ton for reen wood and $28.87 per ton for dry (Arola 1975). Green wood is estimated to yield 4,250 Btu's per ound and a combustion efficiency of 60 percent; ry wood yield is 7,735 Btu's per pound and a ombustion efficiency of 70 percent.) This comparison oes not consider that capital costs for wood burning quipment are higher than for oil fired units. But, here residue is available at low cost, payback eriods are encouragingly short. A similar com- arison for western soft coal, assuming 8,600 Btu's er pound, a cost of $21.50 per ton, and a 70 ercent combustion efficiency, shows a cost of 1.79 per million Btu's. To equal this cost, the roducer could pay as much as $9.11 per ton for reen wood and $19.34 per ton for dry.

Weighting the wood residue not now being used or fuel by its moisture content and related ombustion efficiency, we estimate the material has fuel value of nearly $500,000 as a substitute for il.

SUMMARY

A large portion of the wood residue in the Minneapolis-St. Paul area is produced by a few firms. The largest individual accumulations were at hardwood dimension, millwork, and pallet plants. The bulk of the material was concentrated in the central part of the study area.

Disposal of fine residues is not a problem for study area firms: nearly all of this material is being used. A large portion is sold for animal bedding or burned for heat. On the other hand, coarse residues are costly to dispose of, and nearly two-thirds are discarded as waste.

The residues have several desirable characteristics. Most have a low moisture content and are free of bark. A high percentage of the fine residue are less than 1/8 inch in size, which is desirable for suspension burning. Contamination is not a serious problem, even for most of the coarse residue.

The mixture of species or kinds of material is detrimental for some uses, and low value makes sorting impractical. This is not a problem for fuel, and is the reason this use may be worthwhile considering. Also, it may not be practical to consider manufacturing a product for markets now satisfied from other sources simply because the residue exists.

Because these residues are centrally located, and currently being placed in mechanized dumping containers, it would seem logical the material could be trucked to a central processing station at little additional cost. If used to produce fuel at an existing wood products plant it would then be feasible to invest in processing and boiler equipment. The disposal cost would likely be eliminated for most firms. More importantly, the resource would be utilized.

Now that information is available on amounts, location, and disposal of the material, careful economic analyses can be made for each potential use as prospective utilization opportunities are identified.

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Carpenter, Eugene M.
1977. Secondary wood residue: production, use, and potential in the twin city area. USDA For. Serv. Res. Pap. NC-144, 6 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Presents volume, characteristics, disposal, and uses for wood residues from secondary wood manufacturing plants in Minneapolis-St. Paul, Minnesota.

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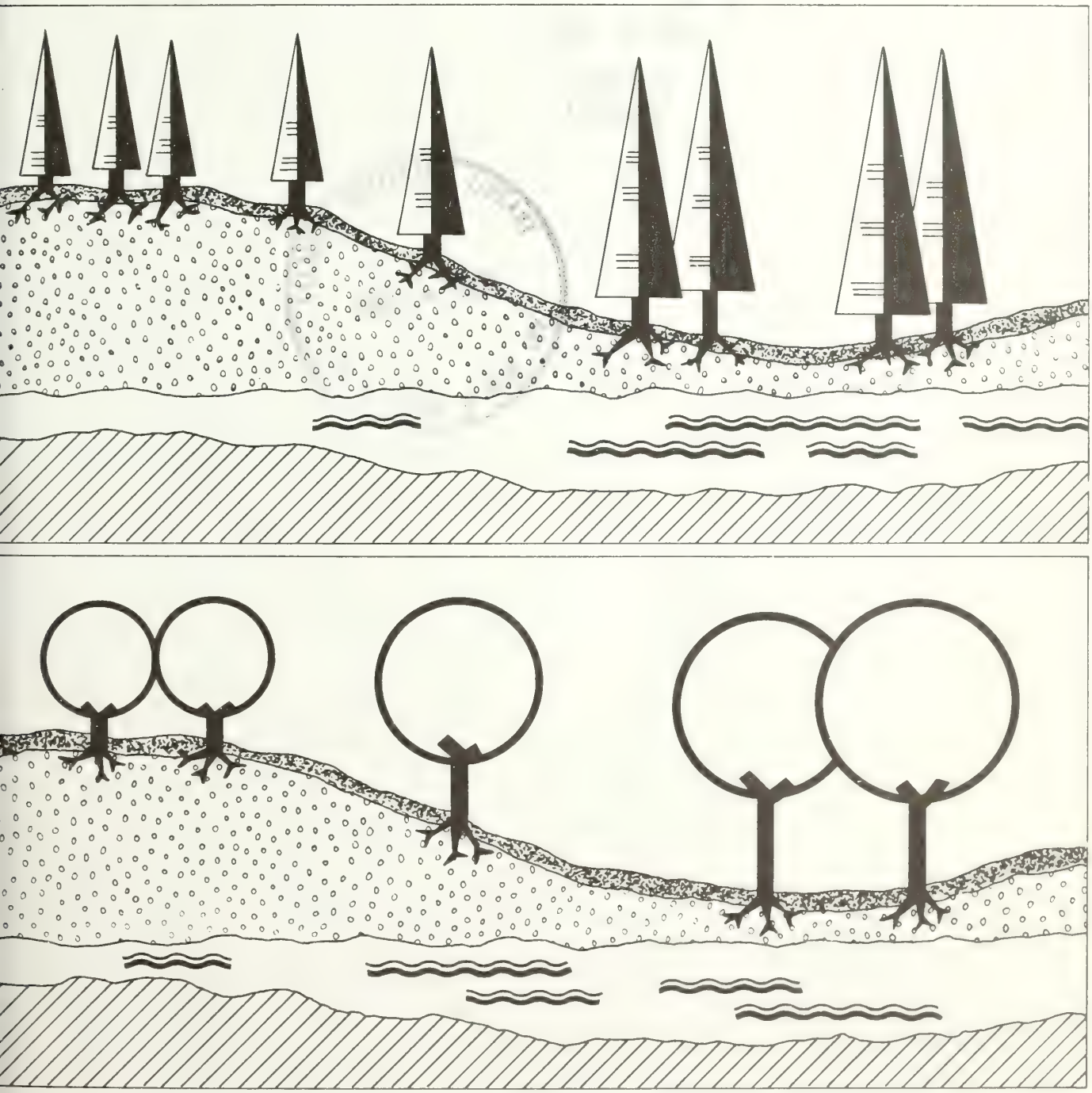
Sing along with Woodsy and help stop pollution.

SEARCH PAPER NC-145

round water differences on PINE and HARDWOOD rests of the Udell Experimental Forest Michigan.

DEAN H. URIE



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1977

GROUND WATER DIFFERENCES ON PINE AND HARDWOOD FORESTS OF THE UDELL EXPERIMENTAL FOREST IN MICHIGAN

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The Udell Experimental Forest was established near Manistee, Michigan, by the USDA Forest Service in 1959 as a field laboratory for studying the hydrology of forested glacial sand soils. One of the major objectives was to compare water yields from the primary forest cover types. Numerous reports have been published on changes in streamflow resulting from reforestation and cutting (Hibbert 1967). In our studies on the Udell, however, we used a new approach. We measured water yield from forested lands as increments of ground water recharge because of the extreme permeability of the soils in the Lake States sand drift area. Surface streams in the sand drift region usually drain large ground water basins that contain a variety of forest vegetation. In order to relate a specific type of vegetation to its hydrologic effects, we had to measure ground water recharge under different types of forest vegetation in a uniform ground water regime. The Udell Experimental Forest provided a variety of forest types in such a simple geologic situation. This report presents the results of 10 years of hydrologic measurements under jack pine *(Pinus banksiana)* and red pine *(P. resinosa)* plantations and under native hardwood forests typical of these sandy outwash plains.

GEOLOGY AND SOILS

The study area consists of sand outwash plains surrounding a sand moraine that resulted from the late Pleistocene (Valders) advance of continental glaciation about 10,000 years ago (Hough 1958). Terminal moraines of the Port Huron Substage were breached and reworked by this ice front and its recessional melt waters to form a large sand plain surrounding small morainal remnants, one of which is the upland known locally as the Udell Hills (fig. 1).

The Manistee and the Little Manistee Rivers flow westward to Lake Michigan through the sand plain. The Udell Experimental Forest lies between these two rivers. Small tributaries to the Little Manistee River form in high water table areas southeast of the Udell Hills. Pine and Claybank Creeks flow from the north side of the area and drain into the Manistee River. The pattern of water table levels shows that ground water flowing from the study area supplies these streams (fig. 2).

Upland soils are predominantly within the Grayling sand soil type, a Spodic Udipsamment. On some ridgetops in the morainal hills, a clayey sand subsoil within the surface 120 cm characterizes inclusions of the Graycalm series (Alfic Udipsamment). Shallow water table areas on the northwest and southeast boundaries contain the imperfectly drained Au Gres sands (Entic Haplaquod) and poorly drained areas contain Roscommon sand (Typic Aquipsamment) interspersed with woody Tawas histosols. Grayling sands cover more than 90 percent of the Experimental Forest.

The depth of the permeable sands was determined by drilling and by surface geophysical methods. Bedrock levels are 590 to 690 ft below the ground surface. Slowly permeable sandy-clay materials were located during drilling at an elevation of about 650 ft at two places on the east outwash plain (points A and B of fig. 2a). Clay surfaces were located at an elevation of 700 ft at two places on the northwest side of Udell Hills moraine (points C and D of fig. 2a).

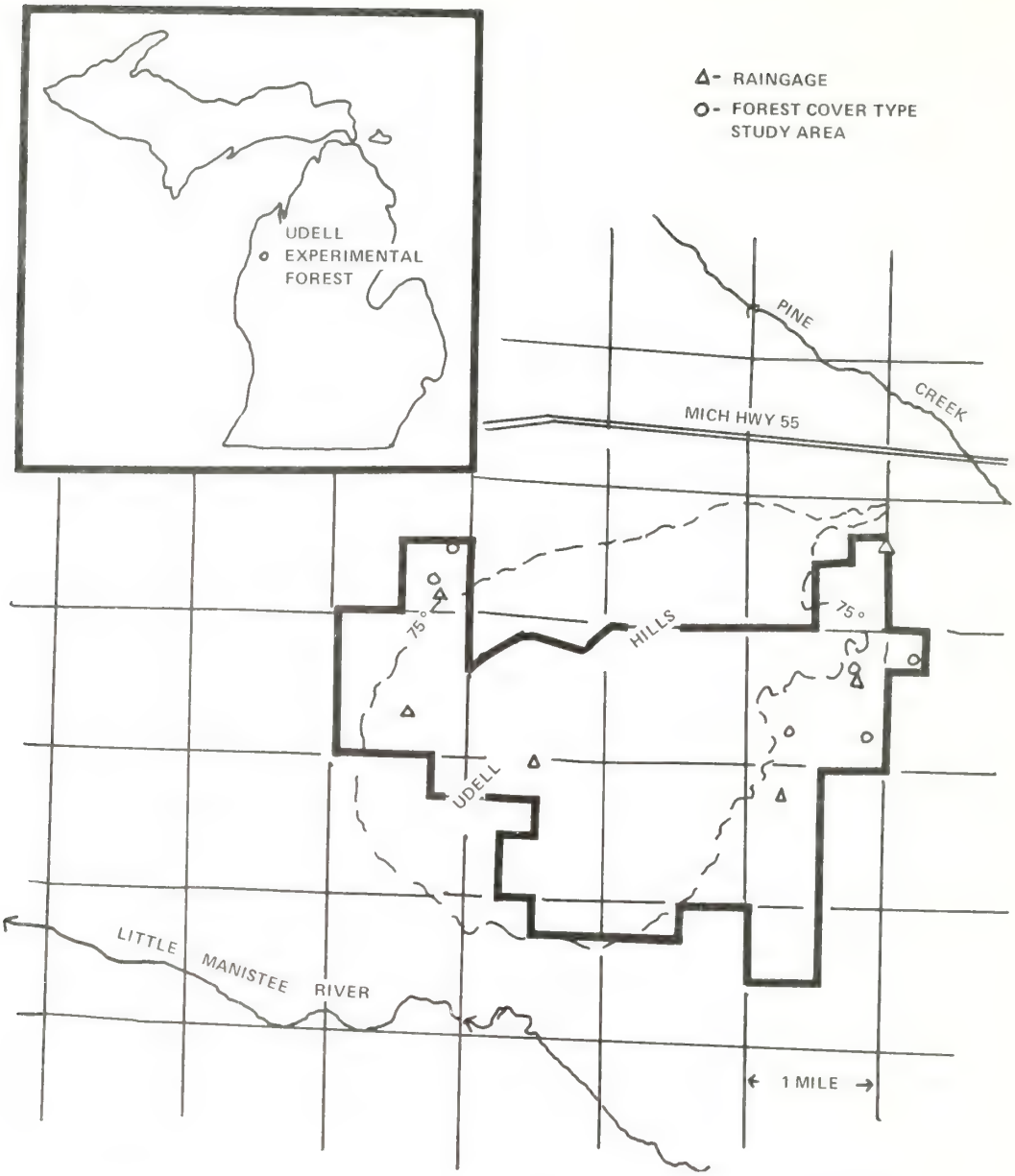

Figure 1.—*Location of Udell Experimental Forest, Manistee County, Michigan.*

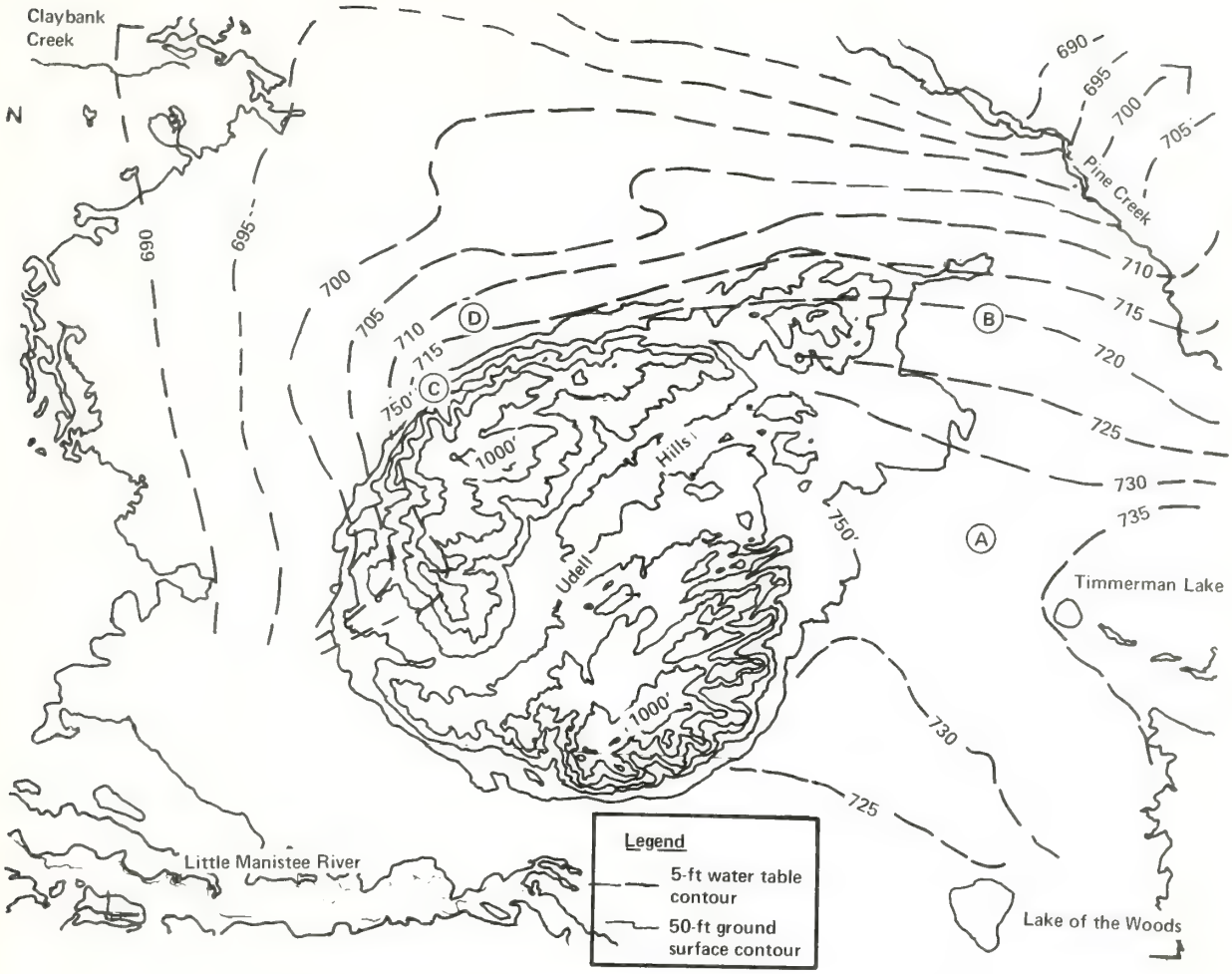

Figure 2a.—*Water table elevations of the Udell Experimental Forest.*

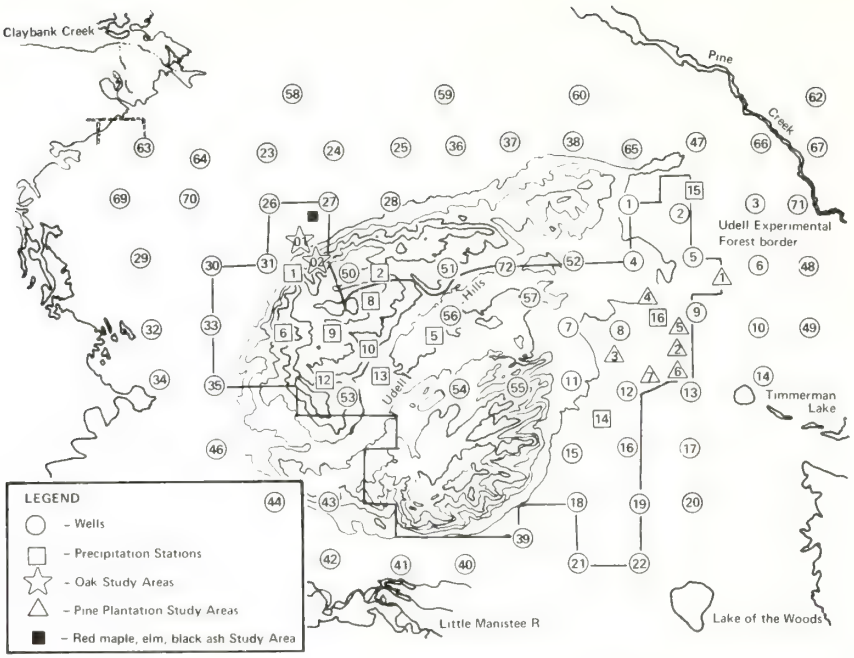

Figure 2b.—*Instrument and well locations of the Udell Experimental Forest. Well 63 is a 1/2-mile grid well net. Wells 45, 61, and 68 and precipitation stations 3, 4, 7, and 11 were never installed.*

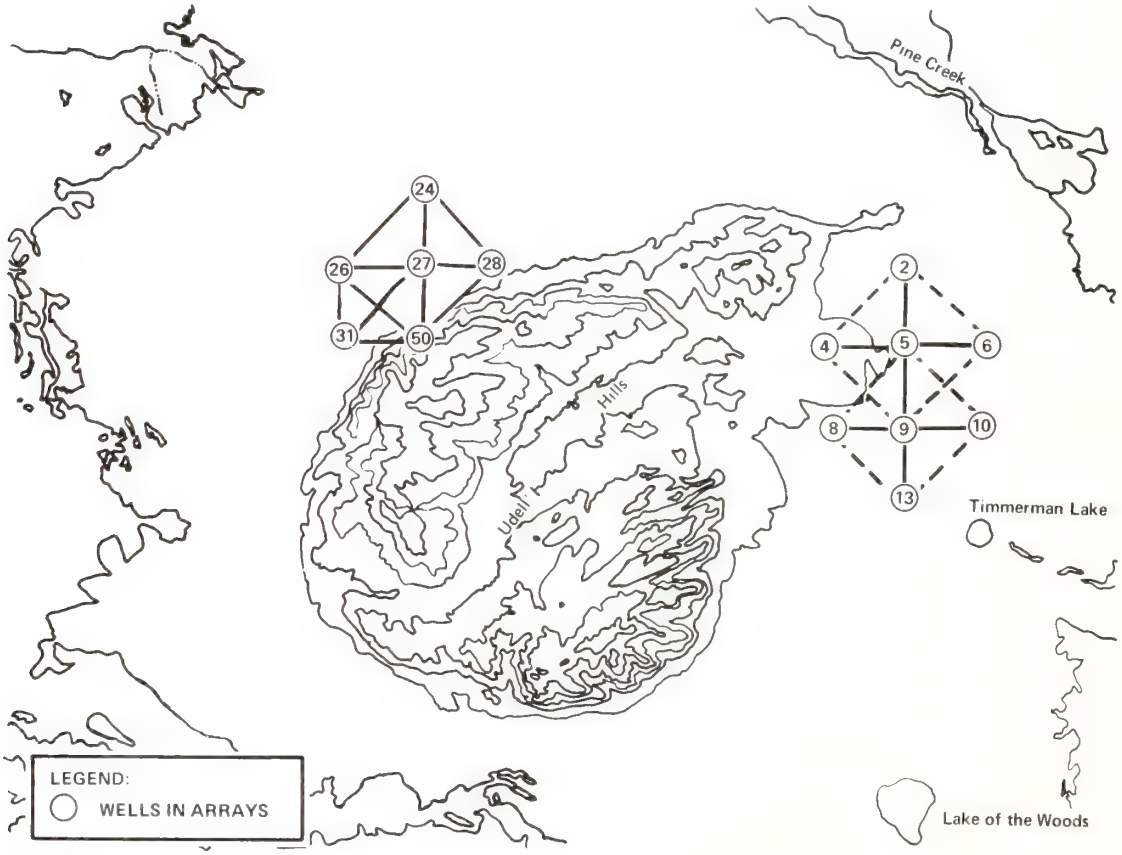

Figure 2c.—*Well arrays used for finite difference analysis of ground water budgets.*

METHODS

A raingage network and ground water observation wells were installed (fig. 2b). Water table measurements under native deciduous forests were made with water level recorders at two sites where water tables were at 21 to 24 m in oak, at one site in a 4.5 to 6 m well in oak, and at one site in a 0 to 1.5 m well in red maple. Well measurements under fully stocked pine plantations were made in two wells that had 4.5 to 6 m-deep water tables and in two wells that had less than 3 m-deep water tables.

These measurements were begun during the period 1959 to 1960 as instruments were installed and are continuing. Supplemental measurements in observation wells arranged in a grid pattern with 1/2 mi between wells were begun in 1960 and continued on a monthly basis through 1969. Snow pack information was obtained for deciduous forests and conifer plantations and subsequently for strip-cut and clear-cut plantations. Snow was measured with a Mt. Rose snow tube along five point courses. Measurements of air temperature were recorded 1.5 m above the ground at precipitation Station 15 (fig. 2b).

Precipitation, Snow-Pack, and Evapotranspiration

The mean value of rainfall and snow catch at the two nearest raingage locations was computed monthly for each ground water budget location.

Snow-pack water content estimates were computed from the mean of the five point snow course data measured on each date.

Estimates of monthly evapotranspiration and water yield were computed using the method of Thornthwaite and Mather (1957). Average precipitation from all gages on the Udell Experimental Forest and mean monthly temperature at Station 15 were used in this computation. Average soil moisture storage in the root zone was estimated to be 76 mm (3 in), for use in this calculation.

All hydrologic computations were summarized by water year (October 1 to September 30).

Ground Water Recharge from Precipitation

Water table elevations were used to compute ground water recharge from excess precipitation by two methods.

Diurnal Fluctuation Method

The analysis of changes in the volume of ground water as shown by water table changes was adapted from procedures developed by White (1932) as outlined by Urie (1966). The process involved three essential steps:

1. The ratio of the drainable pore space to the volume of aquifer dewatered was determined by draining soil columns removed from the zone of water table fluctuations and by relating the rise in water table to depth of rainfall during dormant season storms. The principal variables were time of drainage and depth of the aquifer layer below the soil surface. In comparison to these variables the differences due to particle size distribution were insignificant. For these analyses, gravity yield after 24-hour drainage in relation to depth was used for all wells (fig. 3).

2. The air trapped below a freshly saturated surface soil layer produces an exaggerated recharge pattern in the well record when water tables are 0.6 to 1.5 m below the soil surface (Meyboom 1967) (fig. 4a). This "Lisse effect" creates a problem of separating the well response due to percolating rainfall, which recharges the saturated

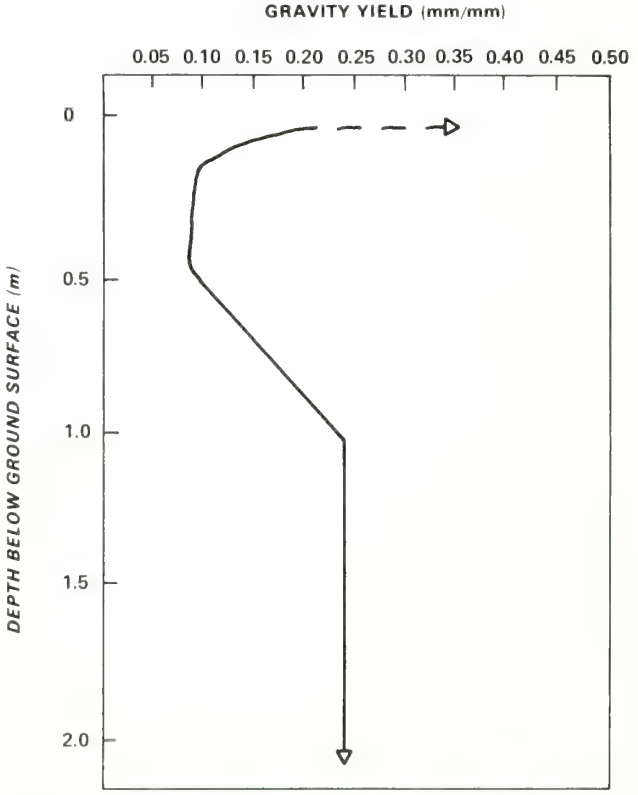

Figure 3.—*Gravity yield of surface aquifer sediments on the Udell Experimental Forest.*

zone. An empirical correction was used on the Udell well records by extending the pre-recharge recession curve 48 hours through the recharge event. Actual recharge due to percolating precipitation was computed from the departure of the well level above the projected recession curve.

When the water table depth is less than 0.6 m from the soil surface in these sand aquifers, the capillary zone extends to the surface and fills 90 to 95 percent of the drainable pore space. This greatly reduces specific yield. The so-called "Weiringermeer effect" is the result of a small amount of rainfall filling the few unsaturated soil pores and raising the piezometric surface as much as 18 times the amount of net rainfall (fig. 4b). Evaporation losses begin immediately after rainfall ceases, quickly removing readily available soil water. The well level recedes almost as quickly as it rose. These fluctuations were analyzed by applying appropriately small specific yield values when the water table was within 60 cm of the surface.

3. Water tables recede faster during daylight hours due to the upward capillary flow to replace evaporative losses in soil moisture. Graphical separation of the recession due to evaporation and that due to regional seepage flow to streams provided a measure of the evaporative demand of forests. These losses were analyzed for differences associated with water table depth, season, and forest cover.

Finite-Difference Analysis of Water Table Surface Method

Periodic measurements of the elevation of the water table for a fixed rectangular grid system of wells were used to compute a pattern of ground water seepage. Changes in well levels for the period were interpreted by use of the gravity yield estimate to compute periodic accretions to the zone of saturation due to vertical movement through the unsaturated zone. The method suggested by Stallman (1956) and used in Colorado by Weeks and Sorey (1973) has been described for the Udell Experimental Forest (Urie 1971). In the present study, data from wells arranged in a grid with 1/2 mi between them were utilized to produce an annual pattern of potential for ground water flow to streams. Annual runoff (ground water yield) values were computed using the sum of periodic products of runoff potential multiplied by the permeability of the aquifer. Aquifer permeability was determined from dormant season estimates of ground water discharge to streams. Annual changes in water table depth, at the end of each water year, weighted by appropriate specific yield values, were added to complete the recharge estimate. An example of these computations at well G-5, which is representative of deep water table pine forest, is shown in table 1.

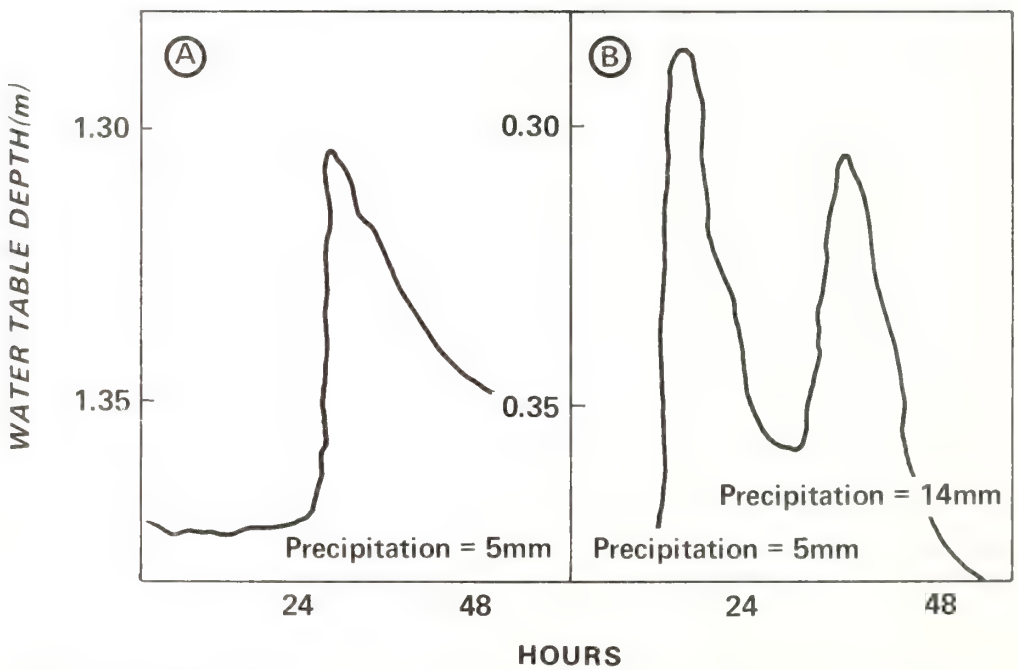

Figure 4.—*(a) Entrapped air "Lisse" effect on well level; (b) rapid well fluctuation near ground surface "Weiringermeer" effect.*

Table 1.—*Computation of annual ground water recharge (water yield), from a pine plantation on a well-drained site for the 1965 to 1966 water year*

Measurement date	$\nabla^2(h^2)$[1] X10-4	Average $\nabla^2(h^2)$ period	Days between measurements	ROgw[2]	ROgw
			Number	*mm/day*	*mm/period*
9/02/65	-1.01				
10/08/65	-0.97	-0.99	8	-1.29	-10
11/05/65	-0.99	-0.98	28	-1.27	-36
12/22/65	-0.48	-0.73	47	-0.95	-45
1/14/66	-0.62	-0.55	23	-0.72	-16
2/15/66	-1.14	-0.88	32	-1.14	-36
3/16/66	-1.34	-1.24	29	-1.61	-47
4/15/66	-1.18	-1.26	30	-1.64	-49
5/25/66	-1.12	-1.15	40	-1.50	-60
7/20/66	-1.15	-1.14	56	-1.48	-83
8/18/66	-1.16	-1.16	29	-1.51	-44
9/15/66	-1.14	-1.15	28	-1.50	-42
10/13/66	-1.17	-1.16	15	-1.51	-23
Total			365		-491

Correction for annual change in Aquifer Storage:

Annual ROgw (net) (mm) = ROgw - $\Delta h Y_g$
where h = annual change in water table elevation
Y_g = specific yield = 0.233
= -491 - (-30-0.233) = 484 mm

[1] $\nabla^2(h^2)$ = Finite difference estimate of ground water outflow potential. (h = annual change in water table elevation.)

[2] $ROgw/day = \frac{P}{2} \nabla^2(h^2)$ = daily outflow of ground water (mm)
P = 26,000 mm/day = effective permeability from solution of
$ROgw = \frac{P}{2} \times \nabla^2(h^2)$ where W = recharge from Q pt. when $W = 0$

RESULTS

Precipitation: The period from 1960 to 1971 included three cycles of wet and dry years (fig. 5a). Well records, which began in 1960, illustrate the high levels of ground water that resulted from a 1958 to 1960 moisture excess.

The period from 1961 to 1963 was generally dry (840 and 764 mm annual rainfall, respectively). Precipitation increased in 1964 and 1965 to 914 and 1,029 mm, respectively. In September of 1965 236 mm of rain sent well levels up in advance of the normal dormant season recharge cycle.

Precipitation in the 1966 water year was the lowest of the period but the hydrological effects were moderate because both the preceding and the following years were the wettest in the decade. The driest period occurred during the summer months, when little ground water recharge occurs even in wet years, thus reducing the effect on ground water levels. In 1967, heavy fall and spring rains resulted in high water yields. Annual precipitation was at or below normal from 1968 through 1971. Extensive rainfall (221 m) in June 1969, produced a rare mid-growing season recharge.

Ground water in relation to water table depth and basin location: Characteristic levels for wells in deep (>15 m), medium (3 to 15 m), and shallow (<3 m) water table situations are shown in figure 6. The swamp well (G-27) showed little carry-over effect from hydrologic conditions of the previous year. The water level follows an annual cycle that has its maximum at the level where surface flooding begins and its minimum at the lowest depth of evaporation drain (about 1.2 m below the surface). Heavy rains frequently produce recharges.

Wells with overburden depths of from 3 to 15 m (G-5) have definite annual cycles of recharge and discharge. The hold-over effect of antecedent conditions is more evident in wells farthest from the stream. It is this reserve storage in the upper basin aquifer that supplies ground water to stream flow during prolonged drought periods. Ground water flow from such extensive aquifers produces the regular streamflow levels characteristic of sand drift region streams (Velz and Gannon 1960).

Well G-50, which has 70.5 m of unsaturated overburden sediments above the water table, showed the greatest time lag in ground water level response to available recharge. Excess moisture in 1967 produced the water table elevation peak in mid-1968.

Well levels were analyzed for the following six hydrologic relations on October 1 of each year from 1961 to 1971 (fig. 6b):

x_1=precipitation during the previous water year,

x_2=cumulative departures of precipitation from the 12-year average generated from Udell Experimental Forest data,

x_3=cumulative 3-year departures from the 12-year average of precipitation,

x_4=annual runoff (water yield) computed from monthly precipitation and mean temperature using Thornthwaite's method,

x_5=cumulative departures of annual runoff from 12-year average of x_4,

x_6=cumulative 3-year departures of annual runoff from the 12-year average of x_4.

Correlation coefficients ranged from 0.64 to 0.95 for the September 30 water table levels in 13 of the wells arranged in a grid. The wells were selected to represent a range of water table depths from <1 m to 10 m. Distance from influent streams ranged from 1.1 to 3.7 km.

Wells furthest from the streams, which also were those with the deepest overburden, were most highly correlated with X_6 (r = 0.86 to 0.95). Well levels closer to the drains, but still with water tables 2 m deep, were

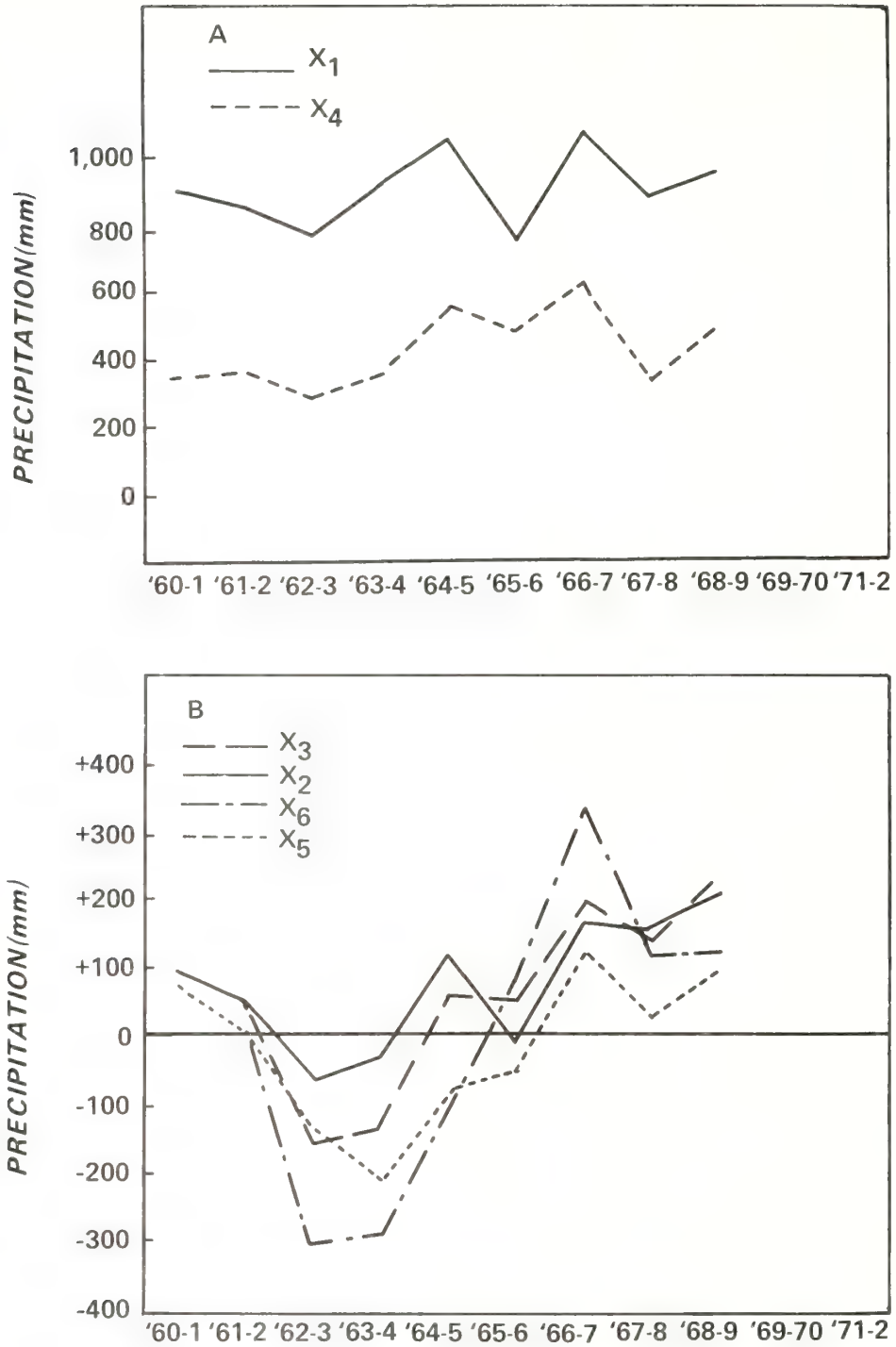

Figure 5.—*Patterns of climatic variables used for analysis of annual water table levels. The patterns of monthly precipitation and runoff were computed from monthly Thornthwaite estimates (Thornthwaite and Mather 1957) (x_1 = annual precipitation; x_2 = 3-year departures of precipitation; x_3 = annual departures of precipitation; x_4 = annual runoff; x_5 = departures of annual runoff; x_6 = 3-year departures of annual runoff).*

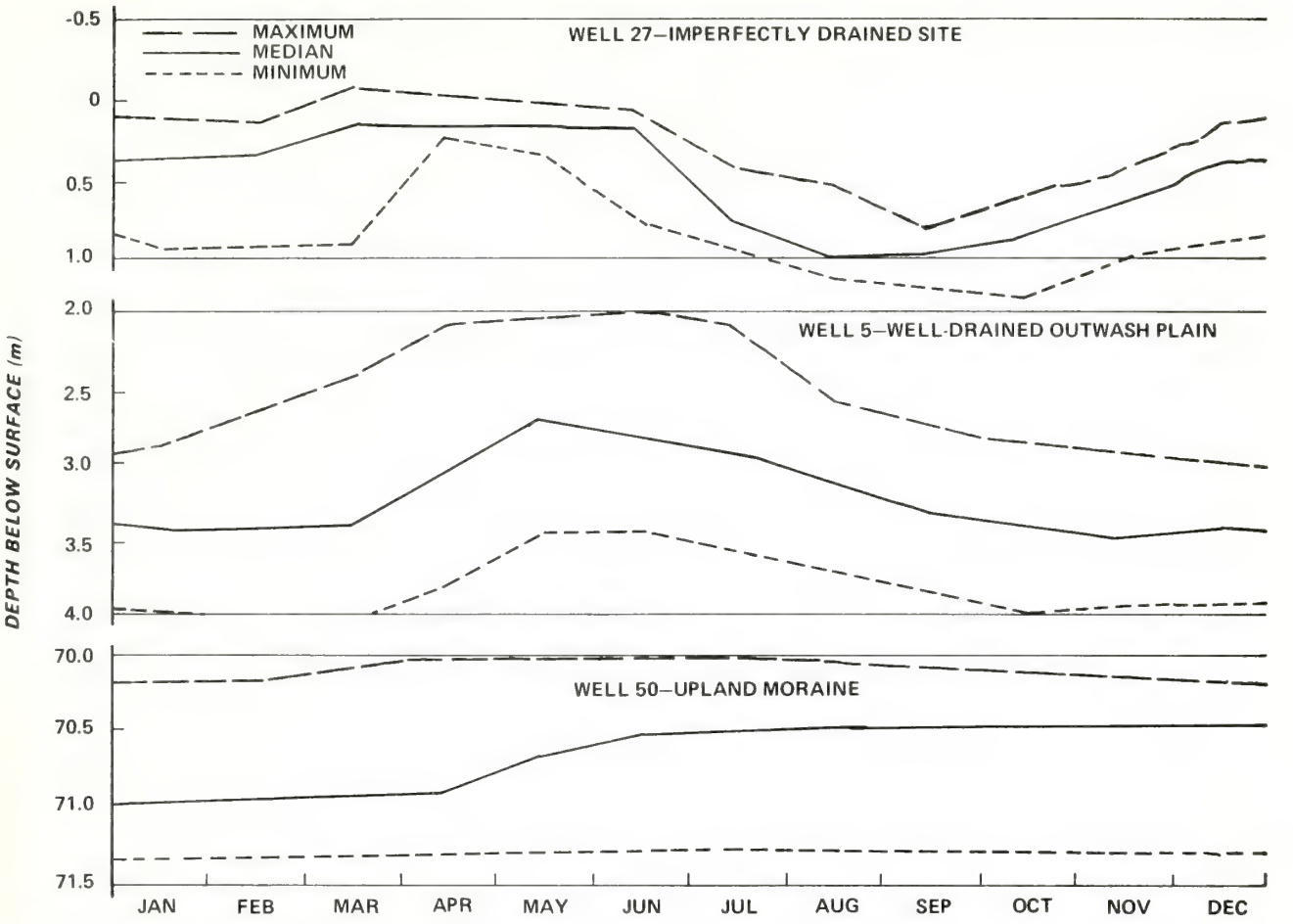

Figure 6.—*Maximum, minimum, and median monthly water table levels at three wells.*

most closely related to X_3. Well levels in shallower water table zones were related to X_1 and X_2 more closely than any other feature tested.

From this analysis it was apparent that ground water levels in deep lying water table aquifers—remote from streams and isolated from the evaporative drain that occurs from shallow water table areas in the immediate vicinity—are closely related to the cumulative water yield computed from climatic data. In this calculation a soil moisture storage buffer is used to balance between wet and dry years.

Shallow water table areas are most responsive to current precipitation and are related to both annual precipitation and cumulative departures from normal precipitation. Soil moisture storage has little effect on water table levels because upward capillarity maintains moisture in the unsaturated zone most of the year.

Water table levels in intermediate zones, which are affected by nearby shallow water table levels, were about equally related to the two measures of precipitation departures from normal (X_2 and X_4).

Comparisons of water yield by cover type: Two alternative uses of sand plain forest lands (native deciduous forests and pine plantations) were compared for water yield characteristics. The most consistent difference was a higher water yield under the deciduous forests on well-drained sites. A less consistent difference was found between the two cover types on shallow water table lands. In 1967, water tables were extremely high, local flooding in two of the shallow water table plots effectively short circuited the ground water flow system. Accordingly, data for this period were dropped from all comparisons between shallow water table forests.

The net monthly and annual recharge of ground water under the four cover-water table depth conditions were analyzed both graphically and by finite difference methods. Annual water yields were computed from October 19, 1961, to September 30, 1971 (table 2).

Table 2.—*Annual water yield estimates (ground water recharge) by forest cover, soil drainage classification, and method of computation (1961 to 1971)*
(In mm)

Water year	Hardwoods				Pine Plantations				Thornthwaite estimate (76 mm)
	Imperfectly-drained		Well-drained		Imperfectly-drained		Well-drained		
	Graph	Finite difference	Graph	Finite difference	Graph	Finite difference	Graph	Finite difference	
1961-1962	327	397	426	457	345	244	367	379	368
1962-1963	374	254	336	423	287	172	293	103	292
1963-1964	469	394	389	403	354	225	338	232	356
1964-1965	557	509	519	574	545	380	502	455	551
1965-1966	394	447	463	528	273	239	364	484	483
1966-1967	[1]620	[1]480	527	664	[1]520	[1]353	504	627	610
1967-1968	434	442	361	528	412	297	309	411	330
1968-1969	473	448	392	523	417	399	353	537	488
1969-1970	311		404		348	345	302		399
1970-1971	343		381		341	380	355		470
10-yr mean	430		421		384	303	369		435
9-yr mean[1]	409		409		369	298	354		415
8-yr mean	456	421	428	512	394	289	379	415	435
7-yr mean[1]	433	413	414	491	376	279	361	384	410

[1] Water year estimates for 1966 to 1967 were dropped from computation due to uncertainty of prolonged flooding effects on imperfectly-drained sites.

Cover type comparisons by either computation method for deep water table areas show that water yield is consistently higher under hardwoods. However, net recharge values in the shallow water table wells (less than 1.5 m) appear to be erroneously high in some years when computed graphically. The net recharge estimate was sometimes greater under shallow water table conditions than it was in the well-drained soils. Because of the high evaporation rate associated with shallow water table lands, these results are obviously in error. As determined in other studies, the finite difference method is more reliable for use in shallow water table conditions (Urie 1971). Therefore, the finite difference values should be used when comparing between cover types.

On well-drained lands that had water tables below the root zone throughout the year the mean water yield under oak was 512 mm (20.2 in), which is 97 mm (3.8 in) more than the mean water yield under pine plantations (finite difference method, 8-year average). Differences between cover types were greatest during the dry years (1963, 1964, and 1968) apparently because of the longer evaporative period in conifers that reduces autumn recharge.

The differences in annual ground water recharge patterns were illustrated by mean monthly ground water increments under the two cover types (fig. 7). Autumn recharge under leafless hardwoods exceeded recharge under pine forests.

A comparison of the hardwood and pine forests on imperfectly drained soils showed a reduction of 32 percent in water yield under pine (413 mm/year for hardwood vs. 279 mm/year for pine).

Snow pack measurements were analyzed to show the influence of conifer crowns in reducing water equivalents during periods of maximum snow accumulation. Snow melted earlier under hardwoods and produced an earlier rise in water tables (fig. 8). Because of this earlier melting under hardwood, the increased ground water recharge due to snow pack differences are spread through March and April and are not evident in figure 7. Daily accretions to ground water recharge during the 1963 melt period are shown in figure 9 for shallow water table pine and hardwood forests. Early melting under the open hardwoods resulted in earlier ground water recharge. Midwinter melt periods often reduce snow pack under hardwood forests, thus spreading the recharge period throughout the winter.

Hardwood forests on the Udell Experimental Forest are found on areas where water tables are high during the early summer. On these sites nearly one-half of evapotranspiration was supplied from the saturated zone. Pine plantations on shallow water table lands were near flood stage in the spring. However, water table depths during summer months under pine were lower than in the "shallow hardwoods". Only about 20 percent of evapotranspiration was supplied to the pine areas from the saturated zone. Because of the different hydrologic positions, cover type differences could not be entirely separated from site.

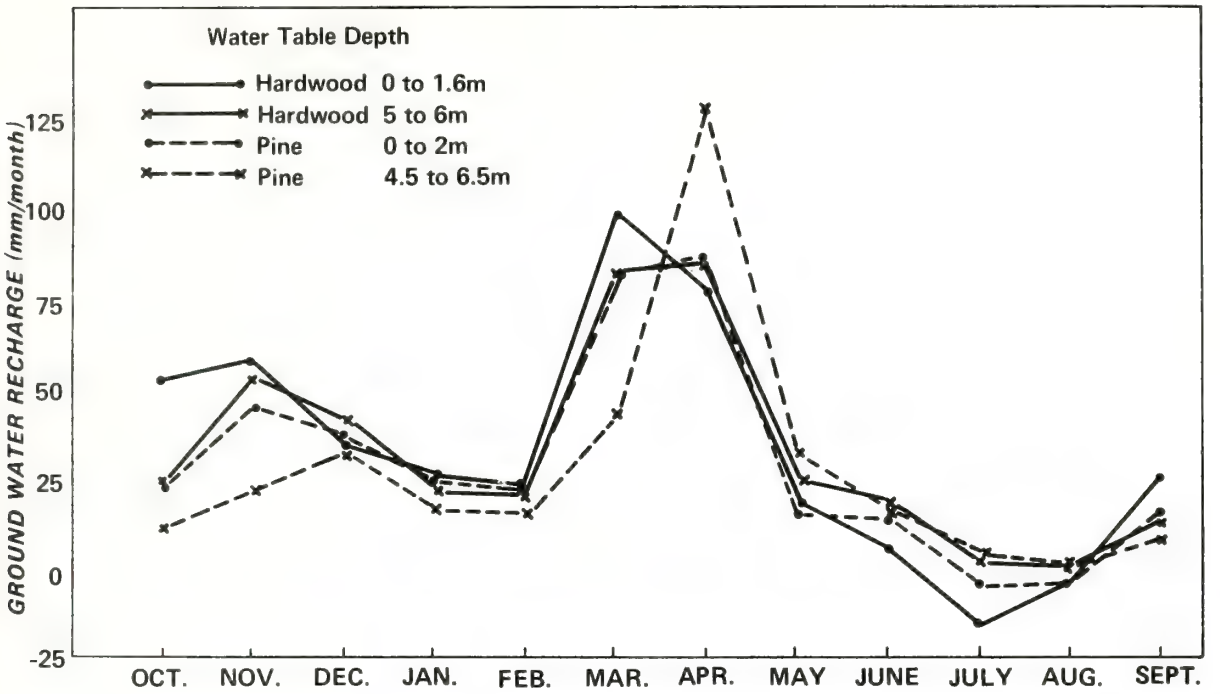

Figure 7.—*Ten-year average monthly ground water recharge by cover type and water table depth.*

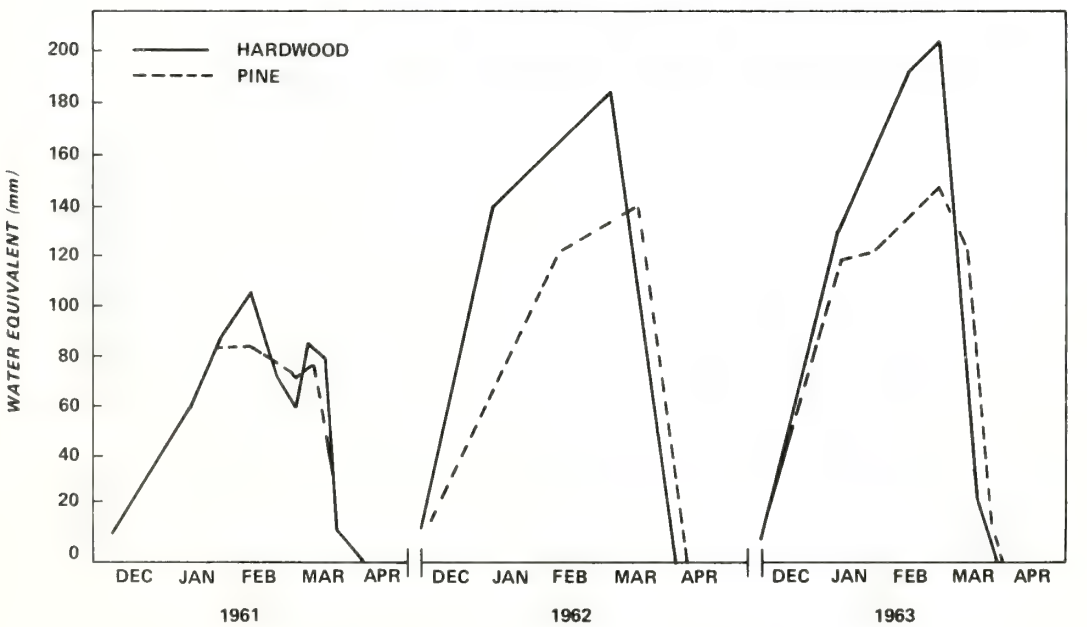

Figure 8.—*Effects of forest cover on snowpack water content, 1961-1963.*

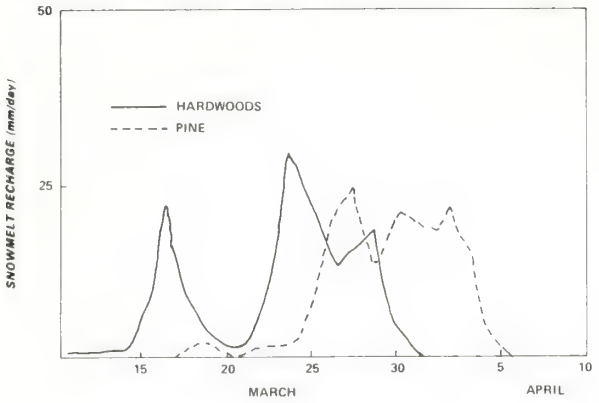

Figure 9.—*Snowmelt effects on ground water recharge, 1963.*

Effects of water table depths on water yields: Comparisons of annual water yields between well-drained and imperfectly-drained sites were made using the finite-difference analyses method. Comparable data were available for 7 water years. Both pine and hardwood forests had lower water yields on the imperfectly drained sites than on the well-drained upland soils. Upland oak forests yielded an average of 491 mm (19.3 in) of water for the 7 years. In a neighboring red maple-elm-black ash forest on imperfectly drained soils the water yield was 16 percent less (413 mm (16.3 in)).

A similar comparison for pine plantations for the same period gave water yield estimates of 384 mm (14.8 in) on well-drained sites. On imperfectly drained lands the same pine species at similar ages yielded 26 percent less annual water yield (279 mm (11.0 in)).

DISCUSSION

Watershed problems in sand drift areas, such as represented by the Udell Experimental Forest, are generally those due to droughty soils and surface instability. These sand areas perform almost ideally as drainage basins. Approximately 50 percent of the annual precipitation is yielded to streams in the form of evenly distributed ground water flow.

The history of Udell ground water behavior illustrates the influence of forest cover on the volume of water produced from a typical sand drift forest area. These records have provided some insights into the location within a ground water basin where forest cutting may result in additional water for augmenting streamflow during prolonged dry periods. Efforts to increase base flow should be made in well-drained lands in the portion of the basin furthest from the streams. Ground water recharge will then flow under well-drained lands to its point of entry into the stream thereby avoiding evapotranspiration losses enroute.

If plantations are established in place of native hardwood forests on well-drained sites, 18 percent (97 mm) decrease in annual water yield will result. Establishing pine plantations on imperfectly drained soils results in a 32 percent (132 mm) decrease in water yields below that of deciduous forests on similar sites. The differences appear during the late growing season and during snowmelt. Forest managers should consider the importance of streamflow maintenance when selecting lands for pine plantings.

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OXFORD: 114.129:116.25(774). KEY WORDS: forest influences, water budgets, evapotranspiration.

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SOIL CHANGES AFTER HAY MEADOW ABANDONMENT in SOUTHWESTERN WISCONSIN

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SOIL CHANGES AFTER HAY MEADOW ABANDONMENT IN SOUTHWESTERN WISCONSIN

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Grand Rapids, Minnesota

Overland flow originating on ridgetop agricultural soils has caused extensive gullying of steep forested slopes in the Driftless Area of southwestern Wisconsin, southeastern Minnesota, and northeastern Iowa (Sartz 1961, 1970). Additional damage occurs where the gullies break out of the woods onto cleared land at the foot of the slope and deposit alluvium containing rocks and boulders. Research in the region has shown that simply abandoning these upland fields does much to reduce the runoff and erosion problem in a short time (Sartz 1970). This improved hydrologic condition is undoubtedly the result of many complex and interrelated biotic and abiotic processes (Parr and Bertrand 1960). Activities of small burrowing animals and freeze-thaw action are perhaps the most obvious of these.

A study was begun in 1969 on the Coulee Experimental Forest near LaCrosse, Wisconsin, to determine the rate that soil properties change after the land has been abandoned and to determine if winter or summer phenomena are most important. It was thought that summer effects would be dominated by biological processes (i.e., earthworm action) and winter effects by physical processes (i.e., freeze-thaw action).

EXPERIMENTAL PROCEDURE

The Coulee Experimental Forest is representative of much of 4.8 million ha (12 million acres) identified by Hays *et al.* (1949) as a "problem area" with regard to runoff and erosion. The topography is a dissected plateau with broad cultivated ridges, steep forested slopes, and narrow cultivated valleys. The ridge soils are primarily loessial Fayette and Dubuque silt loams (Typic Hapludalfs) overlying dolomitic bedrock. Weathering of the bedrock has produced a cherty-clay residuum that has been incorporated into the plow layer where the loess was originally shallow or has been eroded.

The study area was a hay meadow located on a broad ridge. The hay was originally established by underseeding oats with alfalfa *(Medicago sativa* L.). The alfalfa varied in density depending on time since seeding (4 to more than 10 years). The oldest areas were dominated by Kentucky bluegrass *(Poa pratensis* L.), goldenrod *(Solidago* spp. L.), and Queen Anne's lace *(Daucus carota* L.), with only small amounts of alfalfa.

Ten 0.1 to 0.2 ha (0.25 to 0.5 acres) areas all within 1 km (0.6 mi) of each other, were withdrawn from active haying operations in the fall of 1969. Two blocks in each area were permanently marked and divided into seven 1.5 m^2 (5 ft^2) plots. A grid was used to identify nine sampling points evenly spaced at 0.5 m (1.6 ft) within each plot. Seven of the nine points were randomly assigned fall and spring sampling dates beginning with the fall of 1969 and ending in the fall of 1972. On each sampling date (in early May and October, 2 days each) 140 soil samples were collected (7 from each block).

The first season's soil samples were taken with a corer that sampled to a depth of 7.1 cm (2.8 in). During this sampling it became apparent that small burrowing animals were abundant and that

changes in bulk density might be concentrated in the large pore fraction due to the burrowing activity of these organisms. Therefore, subsequent pore volume data were collected separately for large and small pore fractions. These samples were taken with a corer that sampled to a depth of 4.3 cm (1.7 in) to accommodate an air pycnometer. It was felt that the possible confounding effect of the change would be minimal because sampling was in an Ap horizon and when viewed in context with the data from the balance of the sampling dates its effects could be evaluated.

The following variables were determined for each soil sample:

1. Bulk density — gravimetric method
2. Organic carbon — dichromate oxidation (Mebius 1960)
3. Moisture content by weight — oven drying at 105 C
4. Air-filled pores — air pycnometer
5. Water-filled pores — empirically derived from moisture content by weight
6. Total pore space — air-filled pores plus water-filled pores

Percent sand, silt, and clay for each block was determined by the hydrometer method.

As defined, the proportion of air-filled to water-filled pores would be expected to vary from one sampling period to the next simply because of differences in soil moisture content, thereby obscuring changes in proportions related to abandonment. To reduce variation from this source, all soil samples for a given sampling date were collected in 2 consecutive days beginning 48 h after a rainfall sufficient to wet the soil below 8 cm (3 in). Even with these precautions, soil moisture variation between dates was still expected to obscure changes in pore size distribution; therefore, it was necessary to adjust air-filled pore volume for differences related to varying moisture content. The adjusted value was defined as large pore volume and was compared between seasons.

The procedure required developing a regression equation for predicting large pore volume from measured bulk density. Large pore volume was then subtracted from total pore volume to obtain small pore volume. The procedure depended on collecting data under reasonably uniform moisture conditions. It was felt that this criterion could be met within one or more of the sampling dates. The following criteria were used to select the best date: (1) smallest coefficient of variation for measured air-filled pore volume, (2) moisture content at or above filled capacity, and (3) a spring date to minimize evapotranspiration differences between sites. Regression coefficients were then determined using air-filled pore space versus bulk density. Under these conditions, comparable large pore volumes were estimated for each season using the resulting coefficients and measured bulk density.

This procedure was based on the following assumptions: (1) the spatial differences in soil moisture content when at or above field capacity are a function of large pore volume (larger pores drain first), and (2) the relation between bulk density and large pore volume is the same whether measured through space or through time when soils and vegetation are similar. Previous work supports these assumptions (Byrnes and Kardos 1963, Mason *et al.* 1957, Nelson and Baver 1940). Total pore volume was also predicted from bulk density to smooth the curve by accounting for measurement error, and to provide an estimate of total pore volume for the initial sampling date.

For analysis, the two blocks within each area were considered independent because they were positioned on opposite sides, or at different elevations on the ridge. Data analysis followed standard methods for a randomized complete block design and multiple range tests. Simple linear regression and correlation techniques were used to examine relations between soil properties.

During the final summer each abandoned block was paired with an adjacent active hay meadow and infiltration rates were measured. Three single-ring infiltrometers were installed on each half of each pair 4 weeks before measurement. The distance between the paired infiltrometers was less than 20 m (67 ft) to minimize differences in soil depth and texture. The rings were driven approximately 12 cm (4.7 in) into the soil leaving 6 cm (2.3 in) exposed. During measurement the rings were equipped with floats that maintained a constant 5 cm (2.0 in) head. All paired measurements were made simultaneously. Two-hour infiltration rate curves were developed using the mean for the three infiltrometers on each active and abandoned area

After plotting the data it was apparent that steady-state conditions were reached within 60 min. Therefore, the 60-min infiltration rates were examined for significant differences using paired comparisons.

RESULTS AND DISCUSSION

Soil changes progressed more quickly after abandonment than had been expected (table 1). Average bulk density decreased significantly ($\alpha = 0.01$) from 1.28 in the fall of 1969, to 1.16 in fall of 1970, and to 1.10 in spring of 1971, where it remained essentially constant during the following 1-½ yr. Total pore space increased exactly as would be expected (significant at $\alpha = 0.01$) considering the change in bulk density. Organic carbon content also increased significantly ($\alpha = 0.01$) during the 3 yr.

Soil texture differed between blocks as follows: clay 14 to 30 percent, silt 59 to 73 percent, and sand 10 to 16 percent. Clay content was significantly ($\alpha = 0.01$) correlated with bulk density within sampling dates (fig. 1), and on the average explained 36 percent of the between-sample variation. Organic carbon content was also significantly ($\alpha = 0.01$) correlated with bulk density and together with clay content explained 82 percent of the between-sample variation for a given sampling date. The relation of organic carbon to bulk density was examined by Curtis and Post (1964) with similar results. No correlation existed between organic carbon and clay content. As expected, measured total pore space agreed closely with changes in bulk density (fig. 2).

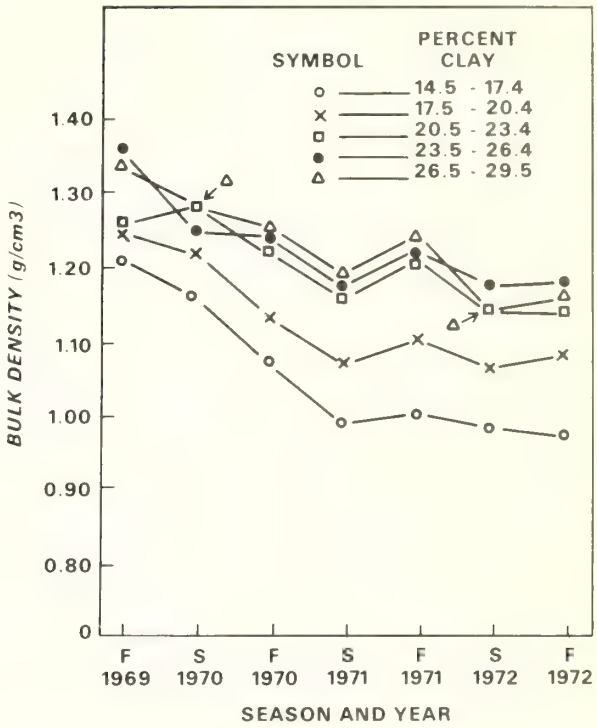

Figure 1. — *Bulk density as affected by clay content (significant at $\alpha = 0.01$) and time (significant at $\alpha = 0.01$). Each point is an average for plots having clay content in the ranges indicated. Measurements made in the spring (S) and fall (F) of each year.*

Table 1. — *Changes in soil properties following hay meadow abandonment*

Measured soil parameter	Season and year[1]						
	Fall 1969	Spring 1970	Fall 1970	Spring 1971	Fall 1971	Spring 1972	Fall 1972
Bulk Density							
Mean (gm/cc)	1.28	1.23	1.16a	1.10b	1.13ab	1.09b	1.09b
SEM[2]	0.018	0.018	0.023	0.025	0.027	0.022	0.021
Organic carbon							
Mean (%)	1.60	1.76	1.98a	2.00a	2.00a	2.20b	2.20b
SEM[2]	0.066	0.068	0.079	0.087	0.088	0.092	0.091
Measured total pore space							
Mean (%)	--	50.4	53.9a	55.4ab	54.0a	56.5b	54.9ab
SEM[2]		0.71	0.79	0.94	0.91	0.79	0.79

[1] Entries followed by the same letter are not significantly different ($\alpha = 0.05$).

[2] Standard error of the mean.

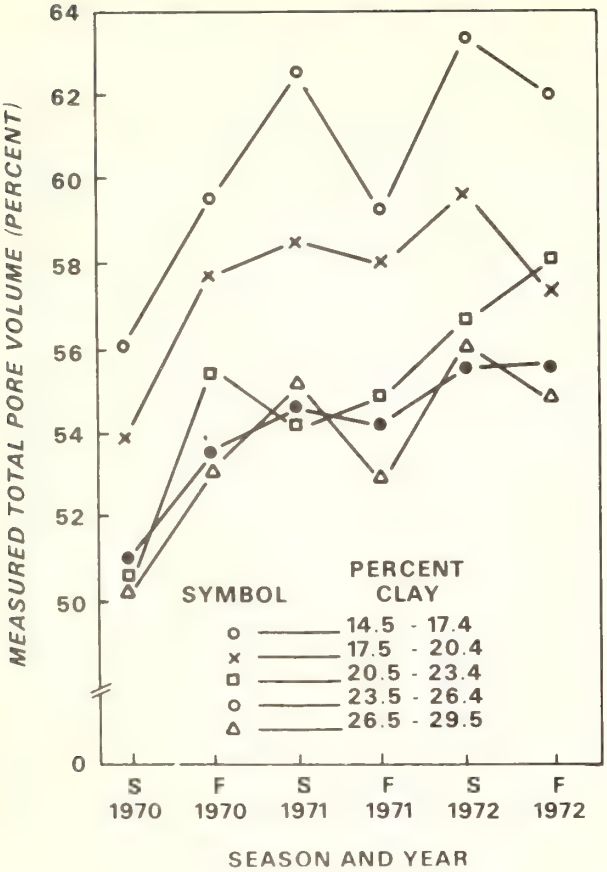

Figure 2. — *Measured total pore space as affected by clay content (significant at $\alpha = 0.01$) and time (significant at $\alpha = 0.01$). Each point is an average for plots having clay content in the ranges indicated. Measurements made in the spring (S) and fall (F) of each year.*

Those plots having soils with high clay content had significantly ($\alpha = 0.05$) higher mean bulk densities (fig. 1). The soils high in clay were located on steep slopes and were the result of either originally shallow loess, extensive sheet erosion, or both. In either case, the clay residuum had become part of the plow layer, increasing clay content at the soil surface. High bulk density associated with high clay content appears to be a long-lasting if not permanent effect. Regardless of clay content, bulk density changes nearly ceased in less than 2 yr. That some processes were still active is evident from the increase in organic carbon.

Total pore volume apparently increased from 49 to 56 percent in 3 yr, based on values predicted from bulk density. As expected, predicted values agree closely with measured values (fig. 3). The

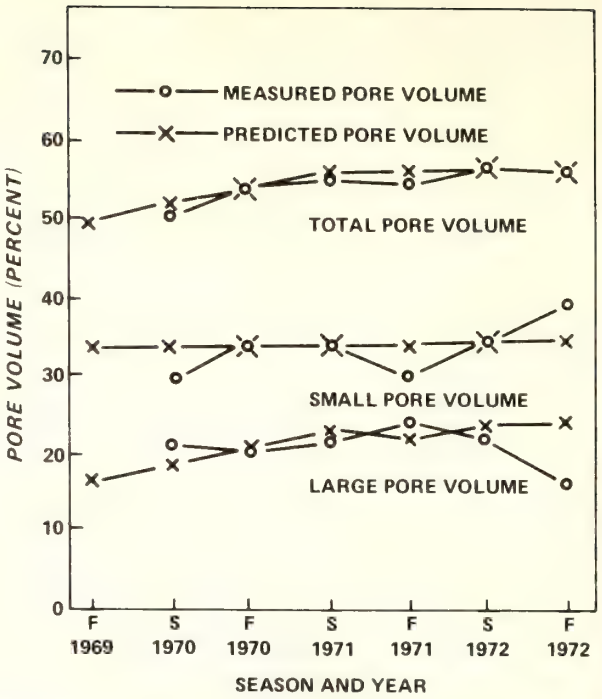

Figure 3. — *Relative change in large and small pore volume following hay meadow abandonment. The predicted pore volumes eliminate the confounding effects of different moisture levels between seasons. Measurements were made in the spring (S) and fall (F) of each year. Regression equations are: Large pore volume (percent) = 50.63 − 26.13 (bulk density), r = 0.88; Total pore volume (percent) = 94.25 − 35.29 (bulk density), r = 0.96. Predicted small pore volume represents the differences between predicted total pore volume and predicted large-pore volume.*

regression equation used to predict total pore volume was derived from pooled data using all sampling dates except the first because no measured values were available for that date. The regression means were linear ($\alpha = 0.05$) for all dates and the slope of the regression lines for each date were not significantly different ($\alpha = 0.05$). Therefore, pooling was justified.

Predicted large-pore volume (essentially non-capillary pores) increased from 17 to 22 percent in 3 yr and predicted small pore volume (essentially capillary pores) remained more stable at 32 to 34 percent (fig. 3). As expected, measured air-filled pore volume was erratic between sampling dates and was not significantly ($\alpha = 0.05$) affected by abandonment. However, after varying moisture

content was compensated for, increased pore volume appears to have been concentrated in the large-pore fraction. Analysis of the relation between measured air-filled pore volume and bulk density indicated that the data could not be pooled for all sampling dates because the regression means were not linear, or, in other words, moisture content varied between sampling dates. However, the slope of the regression lines for each sampling date were not significantly ($\alpha = 0.05$) different. This suggests that, regardless of the mean soil moisture content at the time of sampling, the change in air-filled pore volume as a function of bulk density was always the same. The regression equation selected for predicting large-pore volume was based on data from the spring of 1972 because it best met the criteria mentioned previously.

Changes in bulk density and pore volume improved at equal rates during winter and summer. Although organic carbon increases were not consistent for each sampling period, there was not sufficient evidence to conclude that changes were greater during one season or the other. The sampling periods selected did not separate physical from biological process. Numerous fresh earthworm casts observed during spring sampling showed that earthworms had obviously been active after the previous fall sampling. This masked the role of freezing and thawing, precluding a positive evaluation of this effect on soil properties. The fresh earthworm casts on the soil surface and scattered throughout the matted plant material from the previous growing season were the main evidence of biological activity. Because of the casts' position in the material, they obviously had been deposited after the winter snows had matted the vegetation. The most likely period of activity, ranging from 2 to 4 weeks, was between the time of final snowmelt and sampling. However, some of the activity may have occurred earlier under the snowpack where earthworms were reasonably well insulated from extremely cold weather. Most earthworm casts would be expected in the spring when fresh litter is readily available and soil moisture is high. Telfair *et al.* (1957) noted that the most striking effect of earthworms was a rapid increase in aggregate stability in soil cores containing alfalfa meal. They concluded that alfalfa served as an excellent food for earthworms, encouraging their activity and growth. Similarly, the presence of unharvested alfalfa on abandoned hay meadows may promote rapid soil changes. The importance of an uninterrupted supply of organic material for earthworms was reported by Vimmerstedt and Finney (1973).

The earthworm activity left numerous channels in the surface mineral soil horizon. These channels probably account for the rapid change in bulk density that occurred during the first 18 mo of the study. After that, earthworm activity, although remaining high, apparently tended to close old channels as new ones were being opened, and equilibrium was approached. This explanation is supported by the apparent increase in noncapillary pore space.

Earthworms were probably active in these soils before abandonment; however, continual compaction by heavy farm equipment may have been offsetting their effect. Two to three crops of hay were being harvested annually and it is unlikely that any significant portion of these meadows escaped compaction each year.

As expected, the infiltration rate increased significantly ($\alpha = 0.01$) after abandonment. The mean increase throughout the infiltration curve was approximately 100 percent. Mean 60-min infiltration rates with 95 percent confidence intervals on active and abandoned hay meadows were 9.6 ± 3.3 cm/h (3.8 ± 1.3 in/h) and 20.2 ± 7.0 cm/h (8.0 ± 2.8 in/h) respectively, and are consistent with those measured by Harris (1972) on similar soils.

The change in infiltration rate following abandonment can be related to total storm flow and peak flow for a major storm in southwestern Wisconsin as follows:

	Active (hay meadow)		Abandoned (old field)		Difference
	(cm/h)	(in/h)	(cm/h)	(in/h)	(Percent)
Infiltration rate (this study)	9.6	3.8	20.2	8.0	+110
Peak Flow (Sartz 1969)	6.1	2.4	3.4	1.3	−43
Total Flow (Sartz 1969)	(cm) 2.0	(in) 0.8	(cm) 1.3	(in) 0.5	−35

The measured increase in infiltration rate was directly related to several properties associated with abandonment. However, it is important to keep in mind that the soils studied here had reasonably good structure at the time of abandonment. Also, they were reasonably fertile, had favorable

texture, and had an established and productive vegetative cover. These initial conditions strongly influenced the rate of change that followed abandonment. Apparently, infiltration increased because of the increased number and length of large channels, a relation discussed by Ehlers (1975). Increased soil stability through existence of a continuous standing crop, development of a litter layer, and increased microbial activity all contributed to the increased infiltration rate.

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OXFORD: 181.3(775). KEY WORDS: bulk density, porosity, organic carbon, earthworms, infiltration.

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A Survey of Fishes of the McCormick Forest

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A SURVEY OF FISHES OF THE McCORMICK FOREST

Ronald A. Raisanen, *Graduate Student*
and
J. Kirwin Werner, *Associate Professor of Biology*
Northern Michigan University, Marquette, Michigan

The fish population in the Cyrus H. McCormick Experimental Forest has long intrigued the public. Rumors of lunker bass and trout, the wilderness character of the forest itself, and articles such as Jerry Chiappeta's in *Field and Stream* magazine (May 1970) have done much to sustain this interest. Although the forest is blessed with a pristine character and fish transplants have occurred in the past, a recent survey indicates there is no outstanding fishing for top game species, at least in comparison to surrounding areas. In general, the lakes and streams of the McCormick Forest are bog-like in character, low in productivity, and support only small populations of game fish.

In 1972, the North Central Forest Experiment Station, U. S. Department of Agriculture, Forest Service began investigating the vertebrate fauna of the McCormick Forest. Birds, mammals, amphibians, and reptiles were the subjects of publications by Robinson (1973, 1975) and Werner (1973, 1975). This report describes the fish species present, their distribution, and relative abundance among the four drainage systems within the forest.

METHODS

Canoes and a lightweight john boat were used on most lakes. An 18-foot electrofishing boat or boom shocker was used in sampling White Deer, Bulldog, and Lower Baraga Lakes. Minnow traps were set in the shallows of larger lakes, in ponds, and in all streams. Fyke nets were used in all of the lakes sampled. They were set perpendicular to the shore in water deep enough to cover the net (1.5 to 3.0 m). Gill nets were used in all lakes except Groves Lake; they were set perpendicular to the shore in water ranging from 0.6 m deep at the shore end to 6 m on the lakeward end. Offshore sets were also made in the deeper sections of the larger lakes.

A backpack electrofishing unit was used effectively in rivers and small streams even though the conductivity of the water was generally low. Fishing with plugs and casting equipment, i.e., the hook and line method, was also used to indicate the presence of large predatory species.

Specimens were killed in the field with 10 percent formalin and later transferred to jars with fresh 10 percent formalin in the laboratory. The quality of specimens was very good if the specimens were killed immediately and remained in the killing solution for at least 0.5 hours or longer. Specimens were identified using the taxonomic keys in Hubbs and Lagler (1958), Scott and Crossman (1973), and Trautmen (1957).

A detailed analysis of the man-hours expended for each collecting method and for each location as well as a physical description of the lakes and streams can be found in Raisanen (1976).

Field work extended from May to October, 1975. Sampling of the McCormick Forest was done according to the four drainage systems (fig. 1). The Peshekee River drains the western sections of the forest and flows into Lake Michigamme to the south and eventually into Lake Michigan. The Yellow Dog River drains the northeast and central portions of the forest and flows into Lake Independence which flows into Lake Superior via the Iron River. The Huron and Dead Rivers drain the northwestern and southeastern portions of the tract, respectively, and flow directly into Lake Superior.

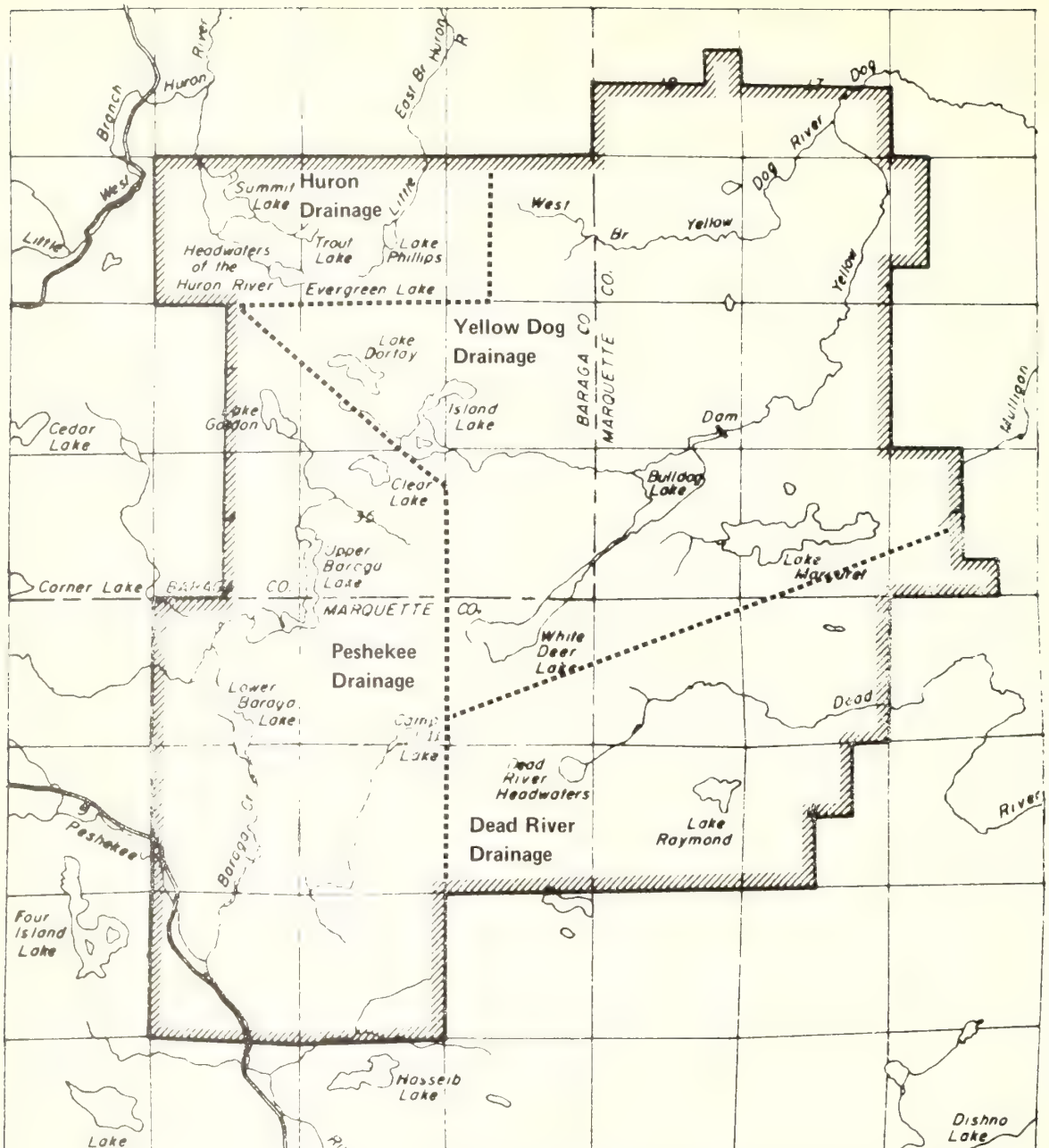

Figure 1. — *Four drainages on the Cyrus M. McCormick Experimental Forest.*

RESULTS

About 2,500 fish were taken in 60 collections throughout the study (Raisanen 1976). More than 1,600 of these were preserved for the Northern Michigan University Museum of Zoology. The remainder were released. Altogether, 29 species from 10 families and 21 genera were represented (tables 1-4). Following is a brief account of the species collected including observations on reproduction and distribution.

Catostomidae — The Sucker Family

Longnose sucker (Catostomus catostomus)

Lowe collected the longnose sucker only from lakes in the Lake Superior drainage (Taylor 1954) and Hubbs and Lagler (1958) considered the longnose sucker as occurring inland only in lakes draining to Lake Superior. The single male specimen we collected was in post-breeding condition and taken in mid-June from Clear Lake in the Peshekee drainage, which is part of the Lake Michigan watershed.

White sucker (Catostomus commersoni)

The white sucker is a very common and uniformly distributed species in the Upper Peninsula (Taylor 1954). This sucker was taken often in the Peshekee and Huron drainages but not in the Dead River or Yellow Dog River drainages. The greatest number was collected from Lake Gordon and Clear Lake when these lakes were sampled in mid-June and suckers were spawning. Lack of suitable spawning habitat could account for the white sucker's absence in all of the lakes of the Yellow Dog drainage and Lake Raymond in the Dead River drainage.

Table 1. — *Species found in the Peshekee River drainage system*

Species	Gordon Lake	Clear Lake plus the Clear Lake outlet	Upper Baraga Lake inlet	Upper Baraga Lake	Lower Baraga Lake	Peshekee River	Camp 11 Lake outlet	Unnamed creek T49N R30W Sec. 2	Relative Abundance[1]
Longnose sucker		X							R
White sucker	X	X			X	X			A
Rock bass				X	X				C
Green sunfish	X								C
Pumpkinseed	X								C
Smallmouth bass					X	X			R
Largemouth bass			X	X	X				C
Mottled sculpin			X			X	X		C
Golden shiner					X				C
Common shiner					X	X			R
N. Redbelly dace		X						X	A
Finescale dace								X	A
Bluntnose minnow		X				X			R
Fathead minnow		X							C
Blacknose dace						X	X		A
Creek chub	X	X	X			X	X		A
Northern pike					X	X			A
Burbot				X		X	X		R
Brook stickleback								X	C
Iowa darter		X							R
Yellow perch	X	X		X	X				A
Logperch						X			C
Brown trout						X			R
Brook trout			X						R
Mudminnow						X			R

[1]A--Abundant (easily collected in large numbers); C--Common (collected often but not in great numbers); R--Rare (seldom collected).

Table 2. — *Species found in the Yellow Dog River drainage system*

Species	Bulldog and White Deer Lake	Margaret Lake	Island Lake	Island Lake outlet	Dortay Lake	West Branch Yellow Dog River below falls	West Branch Yellow Dog River above falls	East Branch Yellow Dog River below falls	Groves Lake	Relative Abundance[1]
White sucker								X		C
Largemouth bass	X		X							C
Mottled sculpin	X		X	X						C
Golden shiner	X	X	X	X						A
Blacknose shiner	X				X					C
N. Redbelly dace	X	X	X	X	X					A
Finescale dace	X	X		X	X					A
Bluntnose minnow	X		X							C
Fathead minnow		X							X	A
Blacknose dace						X				A
Lognose dace						X				R
Creek chub	X			X				X		A
Pearl dace	X	X		X						A
Brook stickleback	X		X	X					X	C
Iowa darter	X	X	X		X					A
Yellow perch	X	X	X	X	X					A
Brook trout						X	X	X		C

[1]A--Abundant; C--Common; R--Rare.

Table 3. — *Species found in the Huron River drainage system*

Species	Summit Lake	Trout Lake	Evergreen Lake	Summit Lake outlet	Little West Branch of the Huron River	Relative Abundance[1]
White sucker	X	X				A
Blacknose shiner			X			R
N. Redbelly dace			X			A
Blacknose dace	X			X	X	C
Creek chub	X			X	X	A
Pearl dace	X	X	X			A
Brook stickleback			X			C
Iowa darter			X	X		R
Yellow perch	X	X				C
Brook trout					X	R

[1]A--Abundant; C--Common; R--Rare.

Table 4. — *Species found in the Dead River drainage system*

Species	Round Lake	Lake Raymond	Dead River	Relative Abundance[1]
Brassy minnow	X			R
Blacknose shiner	X			R
N. Redbelly dace	X	X	X	A
Finescale dace	X			A
Fathead minnow	X			A
Creek chub			X	C
Pearl dace	X	X		A
Brook stickleback	X		X	C
Iowa darter	X			C

[1]A--Abundant; C--Common; R--Rare.

Centrarchidae — The Sunfish Family

Rock bass — (Amblophlites rupestris)

Most of the rock bass caught were small, less than 15 cm total length, and taken with minnow traps.

Several centrarchid nests, presumably made by rock bass, were observed in shallow water (1 m deep) near the Lower Baraga Lake outlet in mid-July. The restriction of rock bass to Upper and Lower Baraga Lakes could be due to the species' avoidance of small streams with moderate to rapidly flowing water, such as the drainages from Clear Lake and Lake Gordon. The absence of rock bass in the other drainage systems in the forest is probably due to physical barriers, falls, rapids, or beaver dams, that extend downstream from the forest boundaries.

Green sunfish (Lepomis cyanellus)

Hubbs and Lagler (1958) considered green sunfish rare in the Upper Peninsula and Lowe collected it from only a few scattered locations including Marquette County. Green sunfish were found exclusively in Lake Gordon of the Peshekee drainage where they were readily caught along with pumpkinseed sunfish in fyke nets set in water 1 to 2 m deep. Many spawning nests possibly made by green sunfish were observed in water about 1 m deep near the shore at the southeast end of the lake. The nests were small, about 0.3 m in diameter, but it could not be determined if they were made by green sunfish or by pumpkinseeds.

Pumpkinseed (Lepomis gibbosus)

The pumpkinseed sunfish is considered native to Michigan and is present in all counties of the Upper Peninsula (Taylor 1954). In the McCormick Forest, pumpkinseed were found only in Lake Gordon but again were readily caught along with green sunfish in fyke nets set in water 1 to 2 m deep. The absence of pumpkinseed in the rest of the McCormick Forest is probably due to the same physical and ecological barriers that have prevented further movement of the green sunfish and rock bass. The spawning nests mentioned in the account of the green sunfish could have been excavated by pumpkinseeds, which spawn at the same time and in a similar manner.

Smallmouth bass (Micropterus dolomieui)

Smallmouth bass are native to the Great Lakes region and have also been planted extensively over the Upper Peninsula (Taylor 1954). One adult smallmouth bass, 48 cm long, and two young of the year were taken from Lower Baraga Lake in late July. Smallmouth bass were not found in the other drainage systems.

Largemouth bass (Micropterus salmoides)

The largemouth bass has been extensively introduced by man and can now be found in all counties of the Upper Peninsula (Taylor 1954). In the McCormick Forest, largemouth bass were planted in White Deer Lake and Island Lake in the Yellow Dog drainage. In addition, largemouth bass were found in several lakes of the Peshekee drainage including Clear Lake, where they were observed to spawn during the month of June. Largemouth bass were not found in the Huron or Dead River drainages.

Cottidae — The Sculpin Family

Mottled sculpin (Cottus bairdi)

Mottled sculpins prefer cool streams but do well in any cool water with a rocky bottom. There is suitable habitat in each drainage system for the mottled sculpin but none were found in the Huron River or Dead River drainages. Low susceptibility to nets and traps could account for their apparent absence from the latter two drainages. Mottled sculpins are often found with brook trout and both species were collected from the Upper Baraga Lake Inlet.

Cyprinidae — The Minnow Family

Brassy minnow (Hybognathus hankinsoni)

Brassy minnows were found only in Round Lake in the Dead River drainage.

Golden shiner (Notemigonus crysoleucas)

More golden shiners were caught in White Deer Lake than any other species from a single location. Golden shiners prefer clear, weedy, quiet waters with extensive shallow areas (Scott and Crossman 1973), which probably accounts for their abundance in the Yellow Dog drainage, particularly White Deer Lake.

Common shiner (Notropis cornutus)

Common shiners were one of the few species taken exclusively by electrofishing gear. Adults were found in Baraga Lake and young-of-the-year in the Peshekee River in August.

Blacknose shiner (Notropis heterolepis)

Blacknose shiners are declining or have been eliminated from parts of their range because of an intolerance towards turbidity (Scott and Crossman 1973). The presence of this species in three of the four drainages of the McCormick Forest is probably a good indicator of the present condition of the water and the forest's history of minimal exploitation by man.

Northern redbelly dace (Phoxinus eos)

Northern redbelly dace prefer small quiet bog waters with detritus or silt bottoms (Scott and Crossman 1973). This type of habitat abounds in the McCormick Forest and it is not surprising that the species was one of four found in all four drainage systems. Only one other species, the creek chub, was found in more locations. Female redbelly dace collected from the unnamed creek in Section 2 (fig. 1) in May contained small, underdeveloped eggs, but those collected from the Island Lake drainage in mid-June and from Groves Lake in mid-August were full of mature eggs.

Finescale dace (Phoxinus neogaeus)

This species was always associated with the northern redbelly dace but was not as widely distributed. The finescale and northern redbelly dace often produce fertile hybrids that are intermediate between both species in pigmentation and size of mouth (Taylor 1954). Several specimens collected from Lake Dortay appeared to be hybrids.

Bluntnose minnow (Pimephales notatus)

Male bluntnose minnows collected from White Deer Lake and Island Lake in July were in breeding condition as evidenced by well developed breeding tubercles on the snout.

Fathead minnow (Pimephales promelas)

Male fathead minnows collected from Groves Lake and Lake Margaret in July had well developed spongy pads on the dorsum from behind the head to the base of the dorsal fin, indicating full breeding condition. Specimens from Clear Lake on the Peshekee drainage and Groves Lake in the Yellow Dog drainage were smaller than those collected from Lake Margaret. Mature males collected from Clear Lake and Groves Lake were 45 to 60 mm long while those from Lake Margaret were 75 to 90 mm long. Specimens from Lake Margaret had a lateral line that was almost complete while those from Clear and Groves Lakes had a lateral line that ended below the dorsal fin. Fathead minnows were very common in Lake Margaret but were not found in White Deer Lake or Bulldog Lake. The latter receives water from Lake Margaret by a short (quarter mile) stream.

Blacknose dace (Rhinichthys atratulus)

The blacknose dace prefers small, swiftly flowing, clear streams (Scott and Crossman 1973) and was encountered in such habitat in the Yellow Dog, Peshekee, and Huron drainages. The falls on the east and west branches of the Yellow Dog seem to block upstream movement, because habitat types are similar above and below the falls yet blacknose dace were found only below the falls.

Longnose dace (Rhinichthys cataractae)

The longnose and blacknose dace, which occupy similar habitat, apparently do not produce hybrids in the wild due to differences in spawning habits (Howell and Villa 1976). In the McCormick Forest, the two species coexist in the Yellow Dog River below the falls with no apparent hybridization.

Creek chub (Semotilus atromaculatus)

Scott and Crossman (1973) considered the creek chub to be one of the most common stream minnows in eastern North America and this proved to be true in the McCormick Forest. The creek chub was found in all drainages and was collected in more locations than any other fish. This species is often associated with the common shiner, and

hybridization occurs where the two coexist. Sympatric populations were found in the Peshekee drainage but there did not appear to be hybridization.

Pearl dace (Semotilus margarita)

The pearl dace is usually found in bogs, lakes, and ponds, typical habitat in the McCormick Forest. Associated with the pearl dace were other bog species including the redbelly dace, finescale dace, brook stickleback, and the fathead minnow. In Michigan pearl dace spawn in clear water 24 to 60 cm deep on sand or gravel bottoms in weak or moderate currents (Scott and Crossman 1973). From our observations, pearl dace may also be spawning in lakes, i.e., Lake Raymond and Evergreen Lake, because, both lakes had large populations of pearl dace but did not have inlets or outlets that were suitable for spawning (seepage only).

Esocidae — The Pike Family

Northern pike (Esox lucius)

The northern pike was collected only from the Baraga Lakes of the Peshekee drainage. It is known to occur in lower regions of the Dead and Yellow Dog drainages outside of the McCormick Forest and thus is probably inhibited from upstream movement by physical barriers such as small, fast-moving streams.

Gadidae — The Cod Family

Burbot (Lota lota)

Three specimens of *Lota lota,* 15 to 30 cm long, were collected from the Peshekee drainage. Burbot are difficult to collect with passive gear except when spawning (under the ice) and were probably missed in some collections.

Gasterosteidae — The Stickleback Family

Brook stickleback (Culaea inconstans)

Brook stickleback were distributed throughout the four drainage systems in clear, cool streams, spring-fed pools, or clear margins of bog lakes. Many were found in association with fathead minnows, northern redbelly dace, finescale, and pearl dace.

Percidae — The Perch Family

Iowa darter (Etheostoma exile)

The Iowa darter was found commonly in clear lakes or slowly moving streams with rooted aquatic vegetation in all four drainage systems.

Yellow perch (Perca flavescens)

Yellow perch were common in all but the Dead River drainage, but are known to be common in the other drainages outside the McCormick Forest.

Logperch (Percina caprodes)

The logperch is widely distributed in eastern North America as well as the Upper Peninsula, but was found only in the Peshekee River.

Salmonidae — The Trout Family

Brown trout (Salmo trutta)

In 1954, Taylor considered the distribution of the brown trout in the Upper Peninsula spotty, but today it is found in many locations throughout the Upper Peninsula and the Great Lakes Region. The occurrence of the brown trout in the Peshekee River is the result of periodic stocking by the Michigan Department of Natural Resources.

Brook trout (Salvelinus fontinalis)

Brook trout were found in the Yellow Dog River and in the connecting waters between Upper Baraga Lake and Lake Gordon. They were reported to occur in the Camp 11 Lake drainage[1] but none were collected in the lower sections of that stream. Apparently attempts made to introduce brook trout into Lake Margaret and Summit Lake were not successful.

Umbridae — The Mudminnow Family

Central mudminnow (Umbra limi)

The single mudminnow specimen collected from the Peshekee drainage is probably not indicative of the range of this species in the McCormick Forest. Suitable habitat is available for the mudminnow in all four drainages but its secretive nature and mud-dwelling existence make it difficult to collect.

DISCUSSION

The bedrock in the McCormick Forest is composed mostly of granite, gneiss, and slate — rocks poor in dissolvable nutrients. The glacial drift tends to be acidic (Forest Service soils report on file at the U. S. Forest Service office in Kenton, Michigan) and the soils have been strongly influenced by poor drainage and a history of conifer forests. Consequently, the lakes formed in the McCormick Forest are acidic, soft, and unproductive. These properties and the dark stained brown water, which is caused by an accumulation of leached humic material from the soil, are characteristic of lakes in bog regions. Clear Lake is the only exception to this in the McCormick Forest, having relatively clear water and a gravel bottom.

The breakdown of organic matter (detritus) through decomposition or aerobic metabolism can decrease or, in extreme situations, totally deplete dissolved oxygen in the water. This can occur at any time of the year in small shallow bog pools but is most likely during the winter when atmospheric oxygen and sunlight are unable to reach the water due to a covering of ice and snow. The following lakes in the McCormick Forest have accumulated so much detritus that winterkill is likely during severe winters with heavy accumulations of snow: Round, Groves, Camp 11, Bortay, Evergreen, Phillips, and possibly White Deer Lake. The remainder of the lakes in the forest have predominantly rock, gravel, and sand bottoms with little detritus.

All of the lakes in the McCormick Forest are shallow. The maximum depth recorded by Campbell (1969) was 7.9 m in Lake Margaret. The soundings and observations made during this study indicate that it is unlikely any of the lakes in the McCormick Forest are deeper than 9.1 m and most are less than 7.6 m deep. Shallow water lakes do not stratify during the summer and are prone to winterkill like those lakes with heavy detritus accumulations.

Drainage Comparisons

Peshekee drainage

Of the four drainages in the McCormick Forest, the Peshekee drainage had the greatest variety of fish: 10 families, 20 genera, and 25 species (table 1). Three of the families, the pike, the cod, and the mudminnows were not only exclusive to the Peshekee drainage but were represented by only one species each, the northern pike, burbot, and the central mudminnow, respectively. Rock bass, green sunfish, pumpkinseed, smallmouth bass, longnose sucker, brown trout, common shiner, and the log-perch were also found exclusively in the Peshekee drainage. Only four species, the brassy minnow, blacknose shiner, longnose dace, and pearl dace, all from the minnow family, were not found in the Peshekee drainage. The abundance of species in the Peshekee drainage is undoubtedly due to the size of the river and its southerly connections via Lake Michigamme and the Menominee River to Lake Michigan. Present species distribution has also been affected by past Great Lakes drainage via the Mississippi River, which afforded entry to the Great Lakes from the Northwest and the upper Mississippi Valley (Hubbs and Lagler 1958, Darlington 1957). Species such as the northern pike, burbot,

[1]*Personal communication with Kenneth Nowell, former manager of the McCormick Forest.*

white sucker, smallmouth bass, rock bass, pumpkinseed, and some of the minnows that utilize or tolerate large rivers, probably entered the McCormick Forest via the present river. The remaining species in the Peshekee drainage, including many of the minnows, the Iowa darter, yellow perch, and perhaps some of those already mentioned, could have followed the retreating glaciers, establishing themselves via presently nonexistent streams (Darlington 1957). The species introduced by man, the brown trout, perhaps the green sunfish, and possibly the largemouth bass, could have established themselves in the Peshekee drainage after being introduced in some part of the Michigamme River or Menominee River drainages.

Yellow Dog drainage

The Yellow Dog drainage had the second greatest number of species and families in the McCormick Forest (17 species from 7 families). However, there were no families exclusive to the Yellow Dog drainage and only one exclusive species, the longnose dace. More cyprinids, both in numbers and species diversity, were collected from the Yellow Dog drainage than from any other drainage. This is most likely due to the lack of predatory fish and/or competition from such species as the sunfish or suckers, plus a variety of favorable habitat. Until recently, when the largemouth bass was introduced into White Deer Lake and Island Lake, the only piscivorous species were the yellow perch and large creek chubs. Golden shiners, fathead minnows, and yellow perch were most numerous while the redbelly dace was most widely distributed.

Underhill (1957) listed specific minnows and darters that were considered as early arrivers after the recession of the glaciers. All of the minnows and the Iowa darter collected in the Yellow Dog drainage (table 2) are included in that list. Species now established in the Yellow Dog drainage apparently did so during or shortly after glacier recession and before the falls on the East and West Branches of the Yellow Dog River became important physical barriers to upstream movement.

The centrarchids, except for the largemouth bass which was introduced, are notable for their absence from the lakes of the Yellow Dog drainage. Apparently ecological barriers (probably stream habitat) of physical impediments (falls or rapids) prevented sunfish from reaching the McCormick Forest.

Huron drainage

Ten species representing 9 genera and 5 families were collected in the Huron River drainage. Brook trout collected outside the McCormick Forest in the Little West Branch of the Huron River about 0.8 km west of Summit Lake are included in the list (table 3). The cyprinids were the most common family in the drainage with five species. Pearl dace and creek chubs were the most numerous and widely distributed fish species. The absence of the yellow perch and the white sucker from Evergreen Lake could be due to the inability of these species to ascend the small intermittently flowing stream between Evergreen Lake and the Little East Branch of the Huron River or lack of suitable spawning habitat.

Dead River drainage

Nine species representing 7 genera and 3 families were collected in the Dead River drainage. The greatest number of fish belong to the minnow family (table 4) as in the Yellow Dog and Huron River drainages. The brook stickleback and the Iowa darter were the only species collected in the Dead River drainage that were not cyprinids. Round Lake and Lake Raymond, the only two lakes in the Dead River drainage, have intermittently flowing connections with the Dead River. Apparently the outlet from Lake Raymond has never been well developed and/or downstream barriers have prevented common species such as the yellow perch from becoming established in the lake. Round Lake is well suited for species, such as the brassy minnow and northern redbelly dace, that prefer small shallow bog ponds or pools.

Species possibly present in the McCormick Forest

The following species collected by Lowe in Marquette and/or Baraga Counties may be present in the McCormick Forest but were not collected: the walleye *(Stizostedion vitreum),* brown bullhead *(Ictalurus nebulosus),* bluegill *(Lepomis*

macrochirus), black bullhead *(Ictalurus melas),* rainbow trout *(Salmo gairdneri),* mimic shiner *(Notropis volucellus),* blackchin shiner *(Notropis heterodon),* and the johny darter *(Etheostoma nigrum).* All of the above are native to the Upper Peninsula except for the rainbow trout, which has been widely introduced and has been planted in the Peshekee River by the Michigan Department of Natural Resources (DNR fish planting report). The walleye and the bullheads were collected by Lowe in the Michigamme and could easily become established in the McCormick Forest via the Peshekee River. The black bullhead was collected from Crooked Lake and the brown bullhead from the Beaufort River (Spurr River on some maps), 8.5 and 12.5 km, respectively, southwest of the McCormick Forest. However, bullheads prefer slow-moving, warm water with soft bottoms and are unlikely to reach the McCormick Forest in the near future if they are not already there. The mimic shiner and the johnny darter were collected from Lake Independence by Lowe; however, physical barriers have probably kept these fish from reaching the McCormick Forest. The blackchin shiner is not a common species in the Upper Peninsula, but it was collected often in the Menominee River drainage in Menominee County by Lowe. It is doubtful that this species has moved upstream as far as the McCormick Forest. Several species of lamprey *(Petromyzontidae)* were also collected by Lowe and could occur in the McCormick Forest.

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OXFORD: 147(774). KEY WORDS: Upper Peninsula, trout, bass, pike, game fish, fish species.

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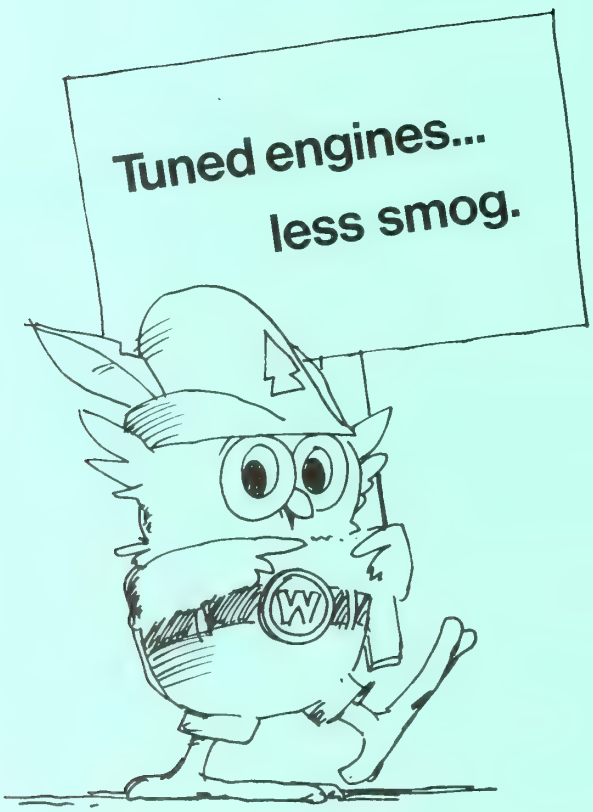
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Role of the WOLF in a DEER decline in the SUPERIOR NATIONAL FOREST

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ROLE OF THE WOLF IN A DEER DECLINE IN THE SUPERIOR NATIONAL FOREST

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The objectives of this paper are (1) to document a severe decline in the numbers of white-tailed deer *(Odocoileus virginianus)* in the Superior National Forest of Minnesota from winter 1968-69 through winter 1974-75, (2) to discuss the probable causes of the decline, and (3) to assess the role of the wolf *(Canis lupus)* in the decline.

Changes in the deer population in this region are important for several reasons. First, a high percentage of campers in the Superior National Forest regard observing deer as an important part of their outdoor experience (Lime and Cushwa 1969). Second, local residents and sportsmen from several urban areas spend considerable time hunting deer in the Superior National Forest. Third, deer form the primary prey of the eastern timber wolf *(Canis lupus lycaon)* in the area (Stenlund 1955, Mech and Frenzel 1971), an animal on the Secretary of the Interior's list of Endangered Species.

THE STUDY AREA

The Superior National Forest, in Cook, Lake, and St. Louis Counties of northeastern Minnesota encompasses some 10,752 km^2 (4,200 mi^2) (figs. 1 and 2). At about 92° W longitude and 48° N latitude, it lies in the northern 20 percent of the deer's natural range (Hall and Kelson 1959). Winter temperatures of -40 C (-40 F) and lower are not unusual, and average snow depths range from 50 to 75 cm (20 to 30 in) (Mech and Frenzel 1971).

Predominant trees in the Superior National Forest before the advent of logging and subsequent fires consisted of balsam fir *(Abies balsamea)*, black spruce *(Picea mariana)*, white spruce *(Picea glauca)*, white-cedar *(Thuja occidentalis)*, jack pine *(Pinus banksiana)*, white pine *(Pinus strobus)*, and red pine *(Pinus resinosa)*. Extensive stands of white birch *(Betula papyrifera)* and aspen *(Populus tremuloides)* developed after widespread logging and fires, and matured, with succession advancing to conifers. Currently about 18 percent of the Superior National Forest is composed of virgin forest, mostly conifers (Heinselman 1973), located primarily in the Boundary Waters Canoe Area, in the northern third of the Superior National Forest.

Although deer inhabited almost all regions of the Superior National Forest during the present century, their densities were highest in recently burned or cutover areas and low in virgin forests (S. Olson 1938, Stenlund 1955).

During winter, deer in the Superior National Forest concentrate primarily in three major winter yards: (1) two strips about 1.6 km (1 mi) wide and 29 km (18 mi) long, adjacent to Lake Superior along the southeast edge of the Forest, called the Jonvick Yard and the Brule River Yard, (2) a more diffuse stretch of variable width from the east end of Lake Vermilion east-northeasterly through Mud Creek, just north of Shagawa Lake to Ely, along both sides of Fall Lake, the Fernberg Road, and northeasterly along Moose Lake and a chain of lakes through Knife Lake, a total length of about 72 km (45 mi), and (3) two strips about 1.6 km (1 mi) wide and 6.4 to 9.6 km (4 to 6 mi) long just north of the Gunflint Trail in the northeast edge of the Forest (fig. 2).

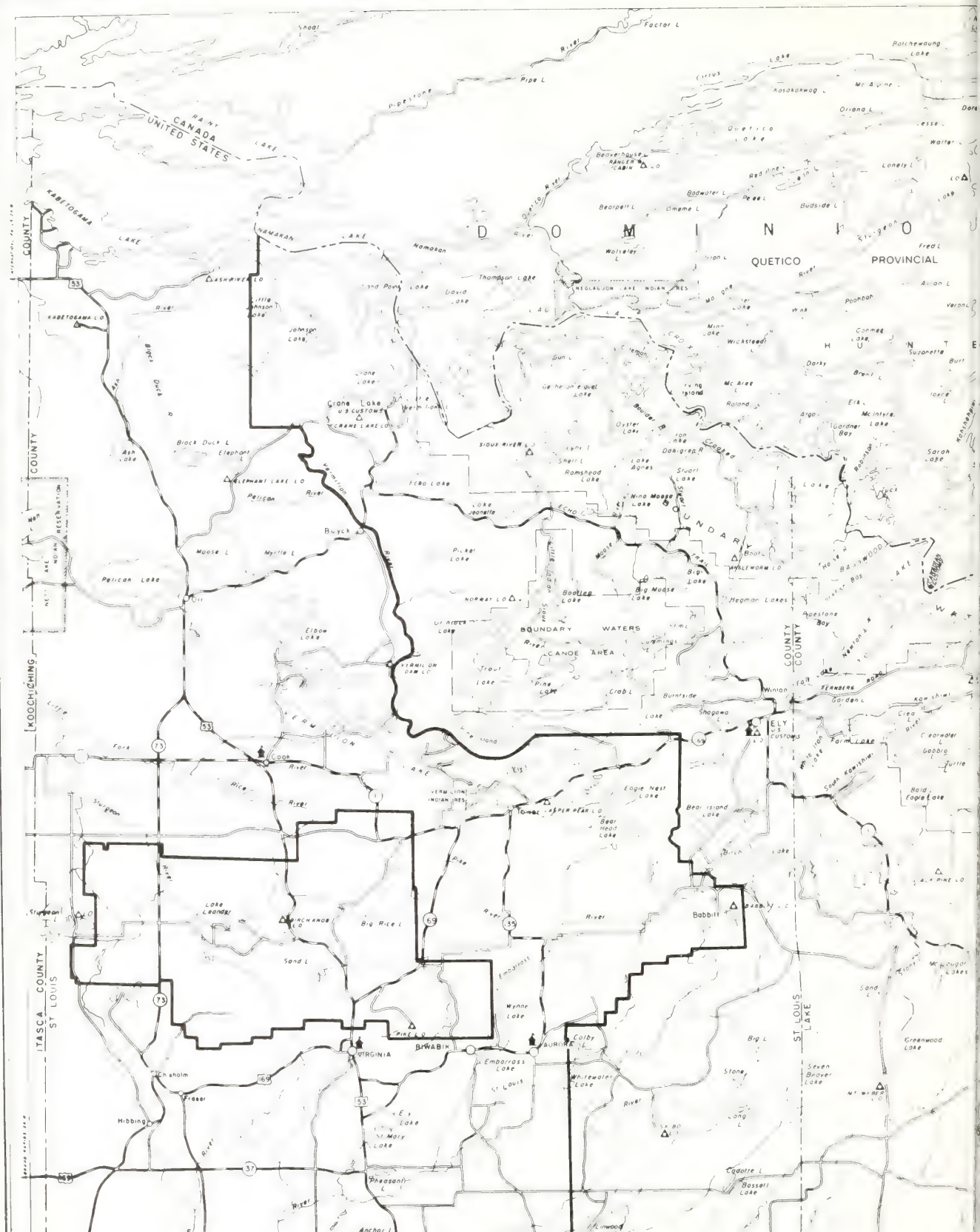
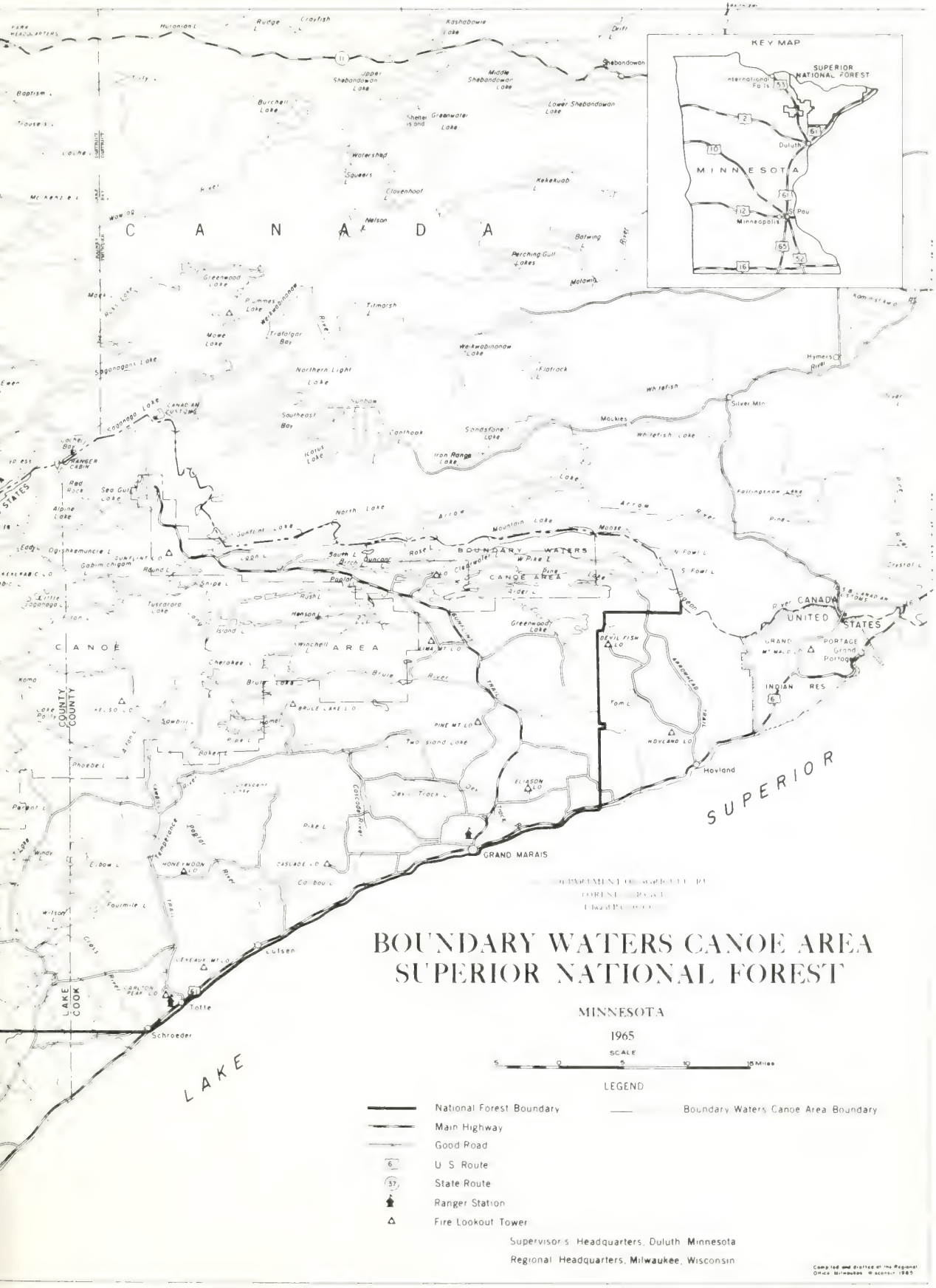


Figure 1. – *Map of the stu*


KEY MAP
SUPERIOR NATIONAL FOREST
MINNESOTA
Duluth
Minneapolis
Pau
CANADA
UNITED STATES
BOUNDARY WATERS CANOE AREA
SUPERIOR NATIONAL FOREST
MINNESOTA
1965
SCALE
5 0 5 10 15 Miles
LEGEND
National Forest Boundary
Boundary Waters Canoe Area Boundary
Main Highway
Good Road
U. S. Route
State Route
Ranger Station
Fire Lookout Tower
Supervisor's Headquarters, Duluth, Minnesota
Regional Headquarters, Milwaukee, Wisconsin
GRAND MARAIS
Hovland
Schroeder
Tofte
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LAKE

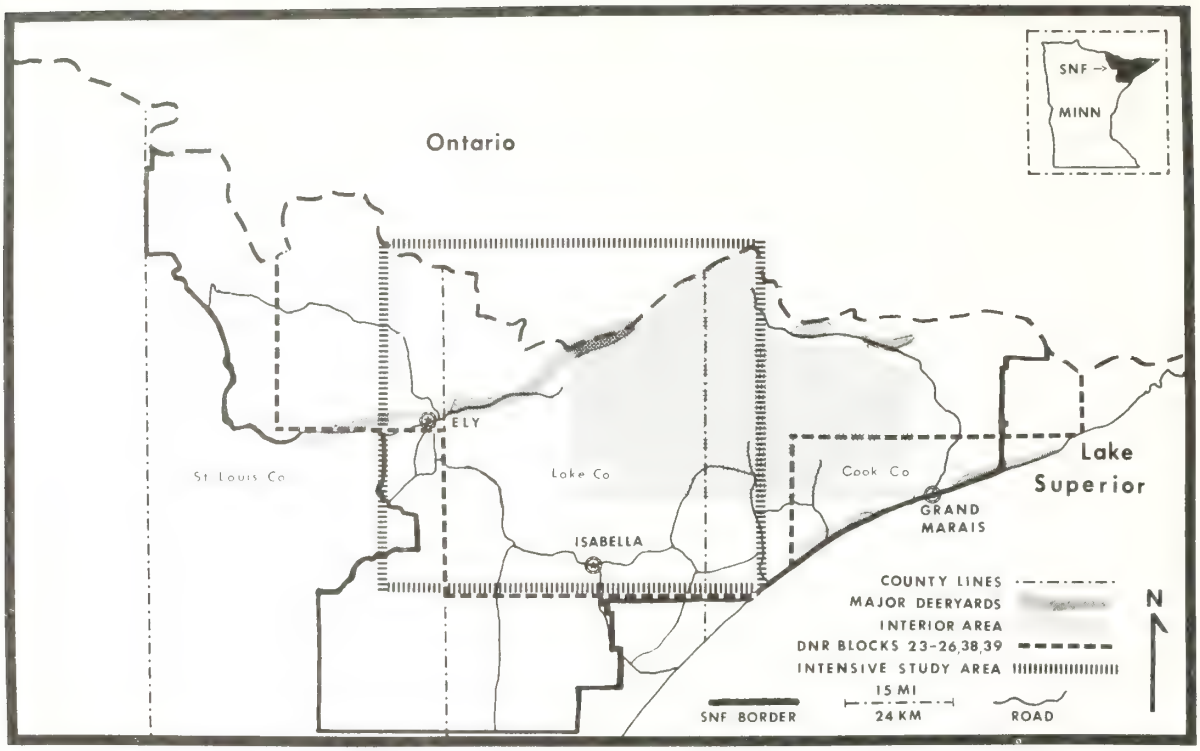

Figure 2. – *The intensive study area in the Superior National Forest. Minnesota Department of Natural Resources Grid Blocks 23-26, 38 and 39 are deer-harvest blocks in which the deer-age-structure sample is considered to best represent deer from the wilderness area. Blocks 14, 15, 22, 37, 50, and 51 lie immediately west, south, and east of the wilderness blocks and are considered to represent the accessible region best.*

The Lake Superior and Fernberg yards are about 96 km (60 mi) apart. In between, yarding also takes place in small, scattered "pockets" near lake shores and in conifer swamps, and in a few yards of up to about 5 km^2 (2 mi^2). Most of the region between the major concentration areas is relatively inaccessible wilderness, to be referred to as the "Interior Area" (fig. 2), consisting of about 3,072 km^2 (1,200 mi^2). Depending on snow and weather conditions, deer begin to concentrate in late fall and early winter and disperse again about April. Movements to yarding areas extended as far as 40 km (25 mi) (H. Olson 1938, Hoskinson and Mech 1976,[1,2]).

Sport hunting of deer is inconsequential in the Interior Area due to the area's inaccessibility. Roads are nonexistent through much of the Interior, and where they do exist in the Boundary Waters Canoe Area, they are closed to mechanized vehicles. Newly formed ice during deer hunting season (November) restricts travel by boat and snowmobile. Deer hunting occurs west, south, and east of the Interior Area, but most of it is restricted to relatively narrow strips along roads, trails, and water ways. The general distribution of hunter-killed deer along the western edge of this area was documented by Mech and Frenzel (1971).

Wolves in the study area prey primarily on deer supplementing their diet with beaver *(Castor canadensis)* from March through November, and with moose *(Alces alces)* (Frenzel 1974, Van Ballenberghe and Mech 1975,[3]). In inaccessible areas, the wolf is the primary agent of deer mortality (Stenlund 1955, Mech and

[1] *Nelson, M. W. 1977. Migration and social organization of white-tailed deer in northeastern Minnesota. Unpublished M.S. thesis, University of Minnesota, St. Paul, Minnesota.*

[2] *Karns, P. D. Unpublished data on file at Minnesota Department of Natural Resources, Grand Rapids, Minnesota.*

[3] *Mech, L. D. Unpublished data on file at North Central Forest Experiment Station, St. Paul, Minnesota*

Frenzel 1971). Along roads in the region bordering the wilderness area, hunting by humans constitutes another important mortality factor.

Wolf control programs by the Minnesota Conservation Department (now the Minnesota Department of Natural Resources) ceased in 1950. Wolf bounties were terminated in 1965, and wolves were protected by the USDA Forest Service on Federal lands within the Superior National Forest beginning in October 1970. In much of the Interior Area, inaccessibility prevented any significant reduction of wolves even before. However packs along the west, south, and east edges of the Interior Area were subject to moderate hunting and trapping pressure. This pressure continued illegally but in reduced amounts after 1970. Wolves were legally protected throughout Minnesota in August 1974 by the Federal Endangered Species Act of 1973.

The wolf population in the Superior National Forest was estimated to be saturated at about one wolf per 25.6 km^2 (10 mi^2) in winter 1971-72 (Mech 1973), with the population organized into pack territories of 125 to 310 km^2 (48 to 120 mi^2) (Mech 1974) and nomadic lone wolves (Mech 1972). From 1972 to 1975, wolves declined about 40 percent in an area of about 2,560 km^2 (1,000 mi^2) in and near the Interior Area (Mech 1977b). Evidence was found there of pup malnutrition (Van Ballenberghe and Mech 1975, Seal *et al.* 1975), disproportionate production and survival of male pups (Mech 1975), decreased litter sizes, and increased intraspecific strife (Mech 1977a, 1977b).

METHODS

We employed several methods to obtain the data presented here. From winter 1966-67 through winter 1974-75, the senior author and his assistant used light aircraft to survey the study area for wolf-killed deer and from 1968-69 through 1974-75 to radio-track wolves (Mech and Frenzel 1971, Mech 1974). Such flights allowed incidental observations of deer and their sign many times each year throughout an intensive study area just east of Ely (fig. 2). Other parts of the Forest were visited often but less regularly. Although only incidental notes were kept on deer seen in earlier years, all deer observed during winters 1972-73, 1973-74, and 1974-75 were noted. During February and March 1972 through 1975, a total of 9 flights involving 17 hours were made deliberately to search for deer and deer sign in the intensive study area. These flights followed all the major waterways and other lowland areas where deer generally yarded in previous years.

In addition, the junior author collected data on (1) the winter severity index [WSI] (Verme 1968) from 1967-68 through 1974-75; (2) fawn:doe ratios and fawn sex ratios in the hunter harvest from 1955 through 1973 (no data for 1971 when the season was closed, or 1974 when only bucks were legal); (3) age structures of hunter-killed does in 1972 and 1973 and of bucks in 1974. The age-structure data were based on jaws and incisors left by hunters at compulsory registration stations and aged according to incisor sectioning (Gilbert 1966,[4]).

Residents who have maintained artificial feeding stations in the Jonvick deeryard were interviewed via telephone regarding the number of deer using their stations each year.

To determine the potential effects of various factors in the deer decline, we used a modeling approach. The basic model involved only the female population and was composed of three empirical parameters: the annual fawn:doe ratios, the annual fawn sex ratios, and an annual wolf population index derived from Mech (1977b). The following assumptions were made: (1) the deer population was relatively stable from 1967 to 1968, (2) therefore, the annual mortality in the herd in 1967 approximated the annual increment, (3) most of the deer dying in the Interior Area were killed by wolves or utilized by them, and (4) annual changes in the wolf population resulted in proportional changes in the annual take of deer by wolves.

In projecting with the above model, we tested the effect of various changes in these assumptions, along with variations in the empirical parameters.

A separate approach to modeling the wolf-deer system in the Interior and surrounding region (DNR Grid Blocks 23 to 26, 38, and 39) (fig. 2) was to adapt the Minnesota Department of Natural Resource's deer population management model (SNOPOP) to allow wolf and deer populations to interact in accordance with the WSI, with estimated wolf consumption rates, and with the wolf population trend.

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[4] *Kuehn, D. W. 1970. An evaluation of the wear method as a criterion for aging white-tailed deer. M.S. thesis, University of Minnesota, St. Paul, Minnesota.*

RESULTS

The Deer Decline

Approximately 1,500 hours of flying were logged during the nine winters of this study, and 454 wolf-killed deer were located, including 142 actually examined by Mech and Frenzel (1971) and 71 examined during the present study. Because the entire study area was repeatedly surveyed each winter, the information obtained can be used to determine changes in deer distribution during the 9-year period.

Of special interest is the eastern half of the study area, including the northern half of Lake County and most of Cook County, much of which composes the relatively inaccessible Interior Area. Unpublished records (Minnesota Department of Natural Resources files) showed that deer inhabited all or part of this area in the 1930's in high densities (fig. 3). Stenlund (1955) then documented the continued existence of deer in the area from 1948 to 1952 (fig. 4). Our own data, including those from Mech and Frenzel (1971), show that deer still wintered in at least the western part of the Interior Area from winter 1966 through winter 1970 (fig. 5).

During the following five winters, however, the usual measures of deer distribution, i.e., wolf kills (figs. 6 and 7) and aerial observations of deer (fig. 8), indicated that the wintering deer population in the Interior Area was depleted.

Although the decline of deer was most dramatic in the Interior Area, deer also decreased outside the Area. This was clearest for winter 1972-73 in two areas: (1) west of Kekekabic and Alice Lakes, and (2) around Bald Eagle Lake, just west of the Interior Area. In the first area, numbers of deer wintered and were killed during at least the previous 6 years, but no deer or kills were found in 1972-73, 1973-74, and 1974-75 (figs. 6, 7, and 8). In the second area, only a few kills and deer were located during 1972-73 and 1973-74 (figs. 6, 7, and 8). This was true even though five radioed wolf packs used the region (Mech 1973), and many kills had been found there during previous winters (fig. 5).

In addition to the loss of deer in these two areas and the Interior Area, several other local concentrations of deer present in earlier years were much reduced or absent in winter 1972-73 (figs. 5, 6, 7, and 8).

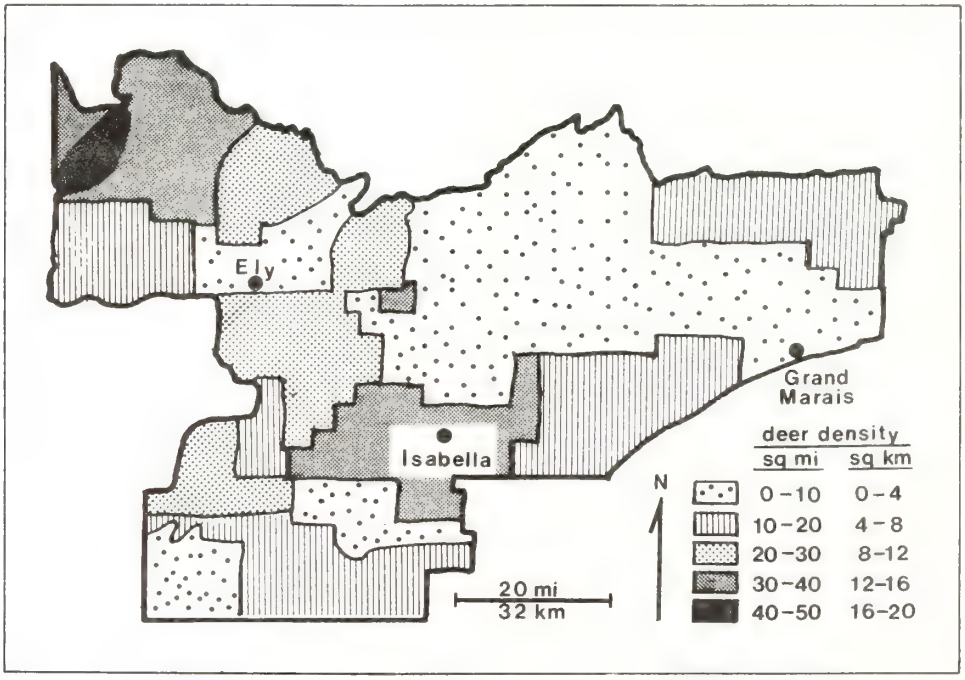

Figure 3. — *Estimated deer densities in the Superior National Forest in 1936, based on extrapolations from deer drives (Minnesota Department of Natural Resources files). Data indicate that areas supporting 0.4 to 4 deer per square kilometer (1 to 10/mi^2) probably had closer to 4 deer/km^2.*

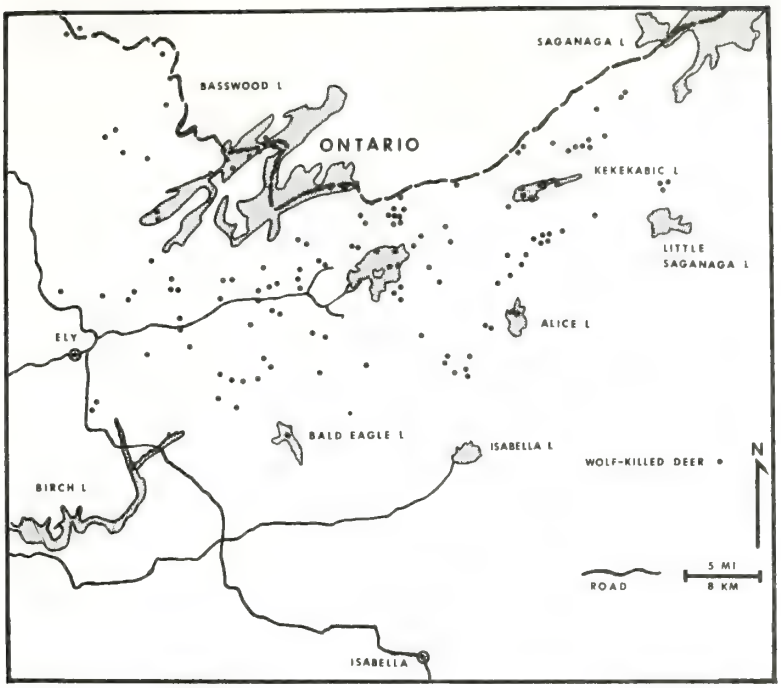

Figure 4. – *Distribution of wolf-killed deer in the intensive study area (fig. 2), 1948 to 1952, reported by Stenlund (1955). No kills were found in the southern half of this region because Stenlund did not include it in his study.*

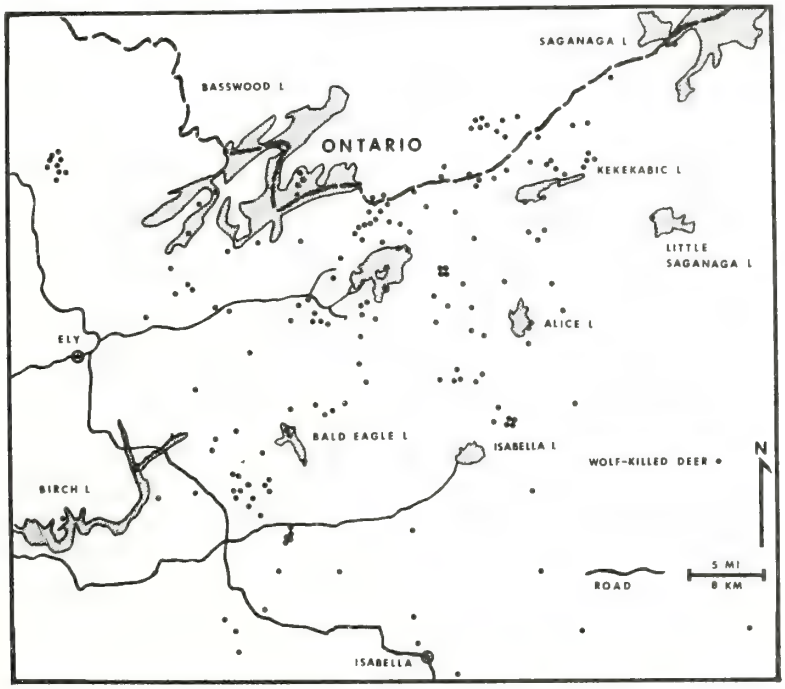

Figure 5. – *Distribution of wolf-killed deer found in the intensive study area (fig. 2) from winter 1965-66 through 1969-70, including those reported by Mech and Frenzel (1971).*

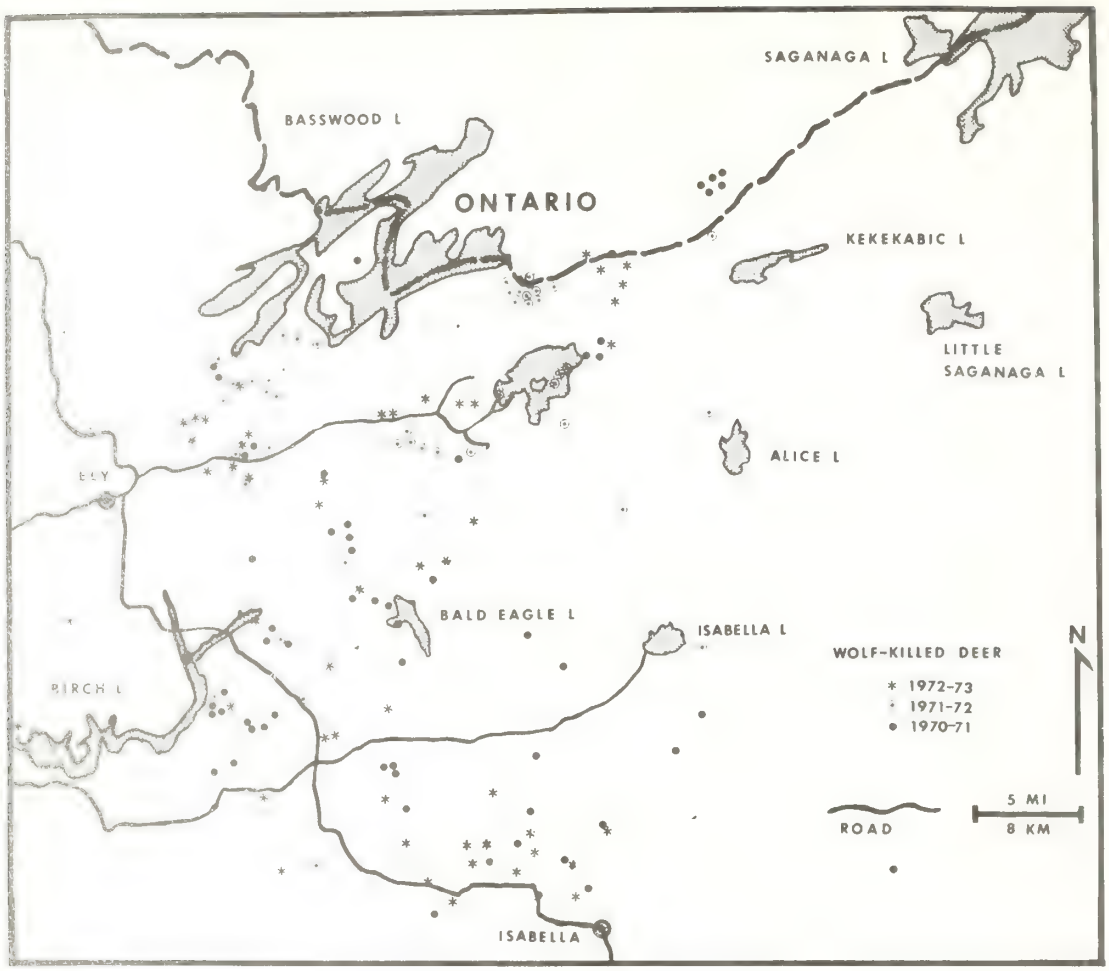

Figure 6. – *Distribution of wolf-killed deer found in the intensive study area (fig. 2) from winter 1970-71 through 1972-73.*

The total loss of the deer populations described above could not be attributed to a shift of these animals into other wintering areas. During the same period, deer populations were greatly reduced in the Fernberg Yard east of Ely (fig. 2), and the remaining deer wintered almost exclusively in the Garden Lake portion of the Yard about 10 km (6 mi) northeast of Ely. This Yard constituted only a tiny fraction of the original concentration area (fig. 2).

In the Jonvick Yard along the eastern edge of the Superior National Forest, the number of overwintering deer also dropped. Local residents who regularly fed deer there during winter were unanimous in their opinions about the trend in the deer population. They stated that deer numbers in their feeding areas had remained stable through most of the decade preceding winter 1968-69 but that thereafter they had steadily declined. The estimated numbers of deer visiting feeding stations in winter 1973-74 were 51 to 73 percent less than in winter 1968-69 (table 1). Pellet counts conducted in the Jonvick Yard in 1959, 1973, and 1976 estimated the overwintering deer population as 55, 45, and 39/km^2 (140, 116, and 101/mi^2).[2]

Table 1. – *Results of interviews with Lake Superior Deeryard residents (Lutsen, Minnesota) who regularly feed deer*

Resident	Maximum number of deer using yard		Decrease
	1968 to 1969	1973 to 1974	
			Percent
Earl Funk	82	40	51
Arnold Peters	81	22	73
Curtis Truman	45	20	56

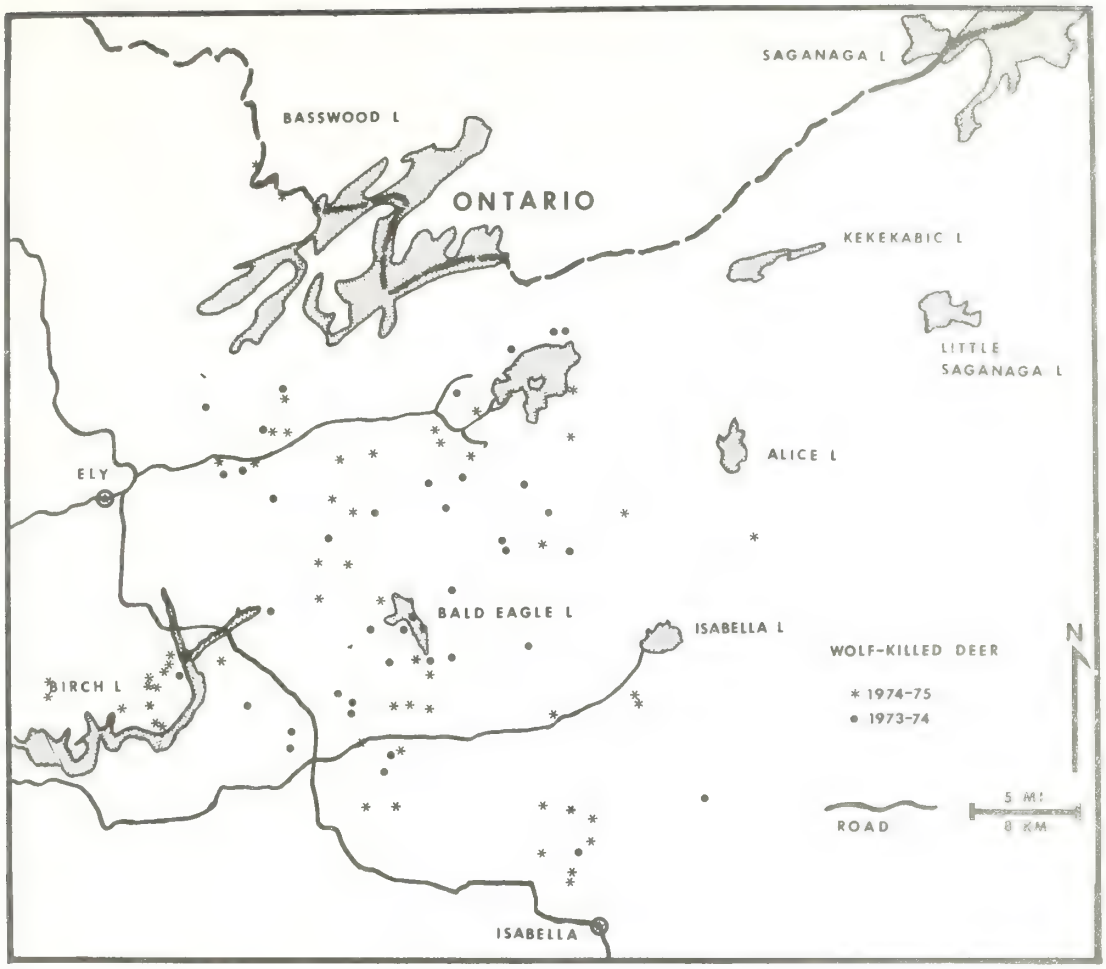

Figure 7. – *Distribution of wolf-killed deer found in the intensive study area (fig. 2) in winters 1973-74 and 1974-75.*

Similarly, deer numbers also declined substantially in the Brule River Yard and the Gunflint Trail Yards east of the study area.[5]

The deer decline in the Interior Area was most noticeable and best documented during winter. In summer, deer that overwintered in the Garden Lake portion of the Fernberg Yard migrated toward the Interior (Hoskinson and Mech 1976,[1,2]), and the same trend took place in the Jonvick Yard (H. Olson 1938,[1]). Thus instead of the absolute lack of deer noticeable throughout most of that region in winter, summer data indicated only extremely low deer densities. For example, in May 1973 the senior author found tracks of deer in only five locations during a 46-km (29-mi) hike of old logging roads in the Interior.

Although the deer decline was absolute in the Interior Area of the Superior National Forest, it took place to some degree throughout northeastern Minnesota, and in the entire Great Lakes Region. Whereas the hunter harvest for Minnesota had fluctuated between 95,000 and 127,000 from 1959 through 1968, it dropped from 103,000 in 1968 to 68,000 in 1969 (Gunvalson 1971). The hunting season was then reduced from the usual 9 days in northern Minnesota to 2 in 1970, and 45,000 deer were killed. The season was closed statewide in 1971.

[5] *Personal communication with W. J. Peterson.*

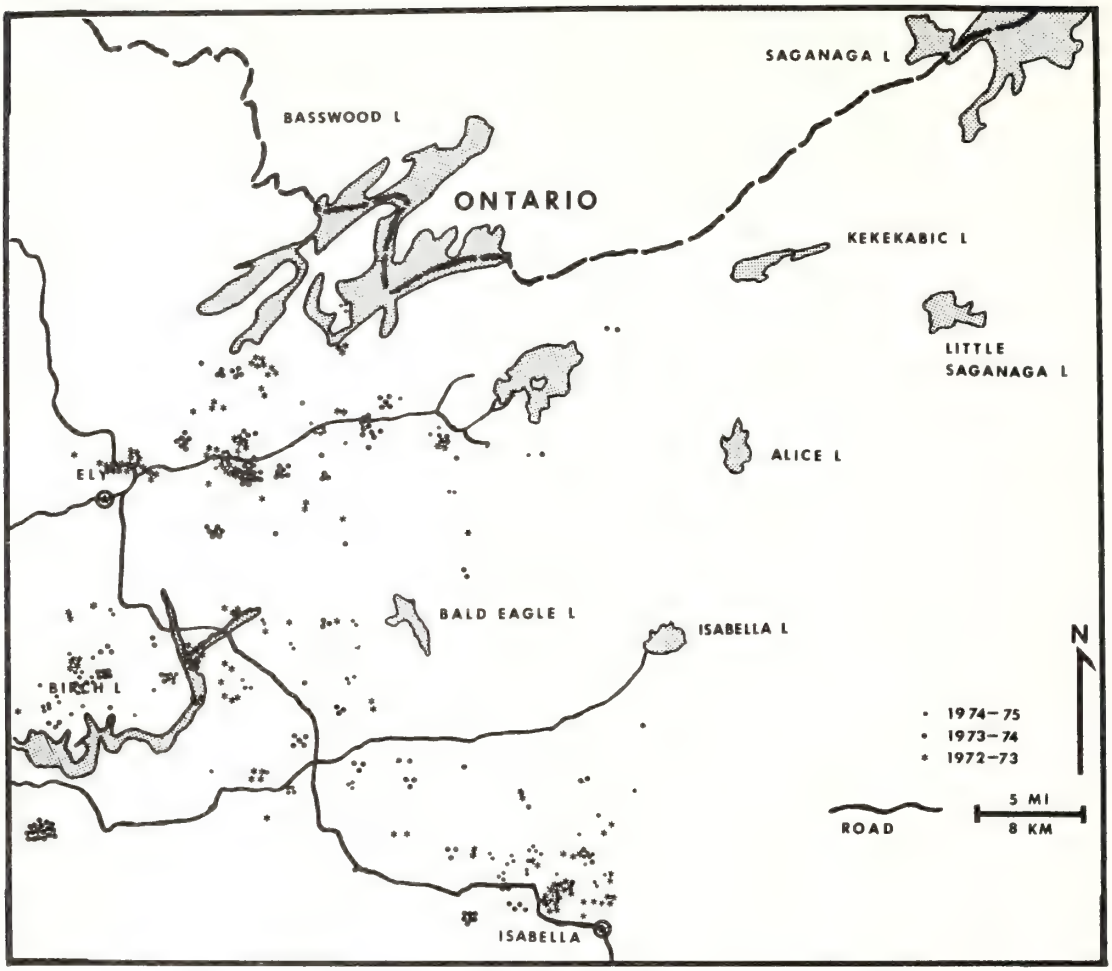

Figure 8. – *Distribution of deer and deer sign observed in the intensive study area (fig. 2) during winters 1972-73 through 1974-75.*

In the study area during 1972 and 1973, the deer season was opened for 2 to 5 days during a 30-day "hunter's choice" framework. Hunters could take deer of either sex and any age before 1974; in 1974, the harvest was restricted to "bucks-only". The hunter kill per 2.6 km^2 (1 mi^2) averaged only 0.83 deer of both sexes in 1973 in the accessible perimeter of the wilderness. In 1974, it averaged 0.54 antlered bucks there. In the wilderness, the hunter harvest averaged 0.25 deer of both sexes in 1973 and 0.13 antlered bucks in 1974.

In central Ontario, indications are that deer declined between 1966 and 1972 (Voigt *et al.* 1976). In both Wisconsin[6] and northern Michigan[7], deer numbers also declined until 1972. However in both States, they then increased each year thereafter.

Winter Severity Index

All but two winters from 1954-55 through 1963-64 were mild in northeastern Minnesota, but from 1964-65 through 1971-72, seven of the eight were rated as severe, and one as moderate (table 2). Verme's (1968) Winter Severity Index (WSI) measured at Isabella (fig. 2) varied from 157 to 270 from 1967-68 through 1971-72, and then dropped to 94 in 1972-73 (table 2), for a 6-yr mean of 177. This was much higher than the means of 112 to 145 for the same years from six other stations in northern Minnesota outside the study area (Agassiz National Wildlife Refuge, Aitkin, Grand Rapids, Togo,

[6] *Personal communication with B. E. Kohn and K. R. McCaffery.*

[7] *Personal communication with R. E. Bailey.*

Norris Camp, and Mille Lacs Wildlife Management Area). A WSI of 100 is sufficiently severe under Minnesota conditions to result in deer mortality[2], just as Verme (1968) established for the Upper Peninsula of Michigan.

Table 2. — *Winter Severity Index and fawn production as evidenced by fall hunter-kill statistics, Lake and Cook Counties, Minnesota*

Year	Winter Severity Index[1]	Fawns per 100 does
1955	Mild	111
1956	Severe	100
1957	Moderate	144
1958	Mild	128
1959	Mild	91
1960	Mild	81
1961	Mild	98
1962	Mild	91
1963	Mild	107
1964	Mild	85
1965	Moderate	71
1966	Severe	72
1967	Severe	90
1968	Severe (157)	66
1969	Severe (190)	65
1970	Severe (164)	71
1971	Severe (270)	--
1972	Severe (196)	51
1973[2]	Mild (94)	85

[1]Preceding winter; numbers in parenthesis refer to Verme's (1968) WSI, measured at Isabella, Minnesota.

[2]Season changed to bucks-only after this year.

Fawn Production and Survival

The fawn:doe ratio is an index of the relative proportion of fawns surviving until fall, and is an indicator of relative fawn production. However, this index is a ratio only. A high ratio, for example, does not necessarily mean a large fawn crop but only indicates a high proportion of fawns produced by what may be a large or small number of producing does. On the other hand, a low ratio definitely indicates a reduced fawn crop, which then may be even smaller if few does are left to produce it.

Fawn production and/or survival, based on fawn:doe ratios from the November hunter harvest, declined substantially from 1955 through 1972, both in wolf-inhabited Lake and Cook Counties and in a nearby, relatively wolf-free area (fig. 9). In Lake and Cook Counties, the fawn:doe ratio averaged 104:100 from 1955 through 1964 (table 2), but then dropped to 71:100 from 1965 through 1973. The fawn:doe ratio was probably very low in 1971, the fall following the record high WSI (table 2), but closure of the hunting season precluded its measurement.

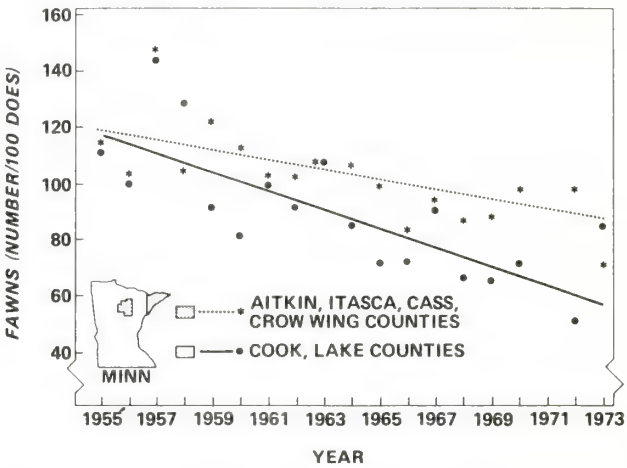

Figure 9. — *Numbers of fawns per 100 does each year in the hunter-kill from relatively wolf-free north-central, and wolf-inhabited northeast, regions of Minnesota, and regression lines for each. For the north-central region, the slope is 1.83 percent per year with a standard error of 11.92; for the northeastern region, the slope is 3.30 percent with a standard error of 15.58.*

Fawn Sex Ratio

The sex ratio of fawns in the fall hunter kill may or may not reflect the sex ratio of fawns produced. However it does generally indicate the ratio surviving to fall, assuming equal vulnerability of the sexes to hunting. From 1955 through 1970, this ratio varied from 35 to 48 percent females in the Lake and Cook County samples, and averaged 41 percent, a difference statistically different from the expected, at the 0.001 level (fig. 10). The ratio was unknown for 1971 and 1974, but in 1972 it increased to 48 percent females, and in 1973 to 52 percent.

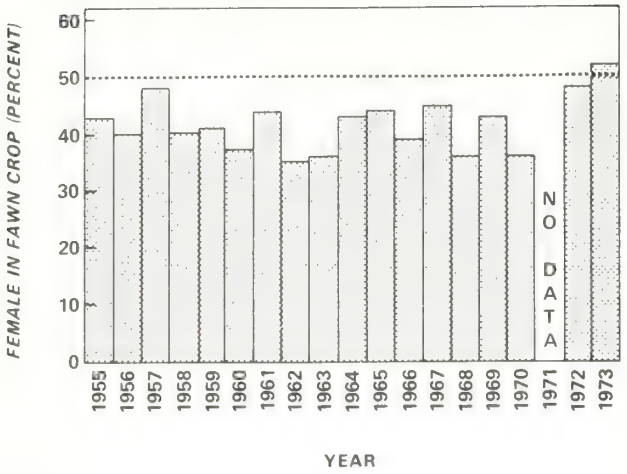

Figure 10. — *Percentage of females in the fawn crop during the hunting season (November) in Lake and Cook Counties.*

Age Structure of the Deer Herd

The age structure data from hunter-killed deer were segregated into those from a region immediately adjacent to the Interior wilderness of the Superior National Forest, and those from more accessible and settled areas adjacent to this region (fig. 2). Wolves inhabited both regions, but human exploitation was much greater in the accessible area. This was because of accessibility, and because the predators were legal quarry in most of the area. Beginning in 1970, they were legally protected in the first region.

In addition, the sample of hunter-killed deer from the more accessible area no doubt included deer primarily from around well traveled roads, active forestry plots, frontier farms, and other areas probably least frequented by wolves. Thus the "wilderness" sample represents a population of deer most influenced by wolves, and the adjacent "accessible" sample represents one that is subject similarly to most natural factors but is less influenced by wolves.

The 1972 and 1973 female age structures appeared basically similar so were combined by superimposing common year classes within each area. The age distributions of does from the wilderness and the accessible regions differed significantly (Kolmogorov-Smirnov, $p=0.01$). The age structure of the sample from the accessible region was generally typical of most deer populations, with each older year class composing a smaller proportion of the total (fig. 11). However, the wilderness sample was highly deficient in the 1969, 1970, 1971, and 1972 year classes.

Age-structure data were available for bucks only in 1974. In both wilderness and accessible regions, the male age structures (fig. 11) were much closer to typical than was the female age structure for the wilderness area. The 1970, 1971, and 1972 age cohorts made up a considerably greater proportion of the male populations than they did in the female population in the wilderness, although the 1969 class was disproportionately low just as in the female samples (fig. 11).

The trends seen in the various age structures were also reflected in the mean ages of the samples (table 3). The samples of the oldest deer were those from the wilderness does, with a mean age of 5.3 years in 1972 and 4.7 in 1973, excluding fawns. Does in the accessible areas had a mean age of 3.5 years. The samples of the youngest deer were those of the 1974 bucks, 2.5 years for those from the accessible area, and 2.6 for the wilderness sample. These ages were even younger than the mean ages of the samples of bucks taken in 1967 and 1968 before the drastic decline (table 3).

The above figures strongly suggest that survival was greater for male fawns than for female fawns during the decline, but that the reverse was true for adults. This difference is supported by the fact that the oldest animal in the larger sample of bucks in 1974 was only 7.5 years old, whereas the oldest doe was 10.5 years. (The above interpretations all assume that the relative vulnerability of the various age classes of deer to hunters was approximately the same in both areas.)

DISCUSSION

The severe decline of deer in the Superior National Forest raises the question as to the cause or causes of the decline. One of the most conspicuous and pertinent pieces of information available is the long range, decreasing trend in production of fawns in both northeastern and central Minnesota (fig. 9). Because these two areas differed in winter severity, hunter density, vegetation types, and habitation by wolves, some other factors seem responsible. Circumstantial evidence suggests that nutritional influences related to increasing forest maturation and succession may be the major factor.

The effect of poor nutrition and low quality range in reducing deer productivity has long been recognized. Deer on poor diets shed fewer ova (Cheatum and Severinghaus 1950), and produce fewer fawns (Verme 1965, 1969) and fawns of decreased viability (Verme

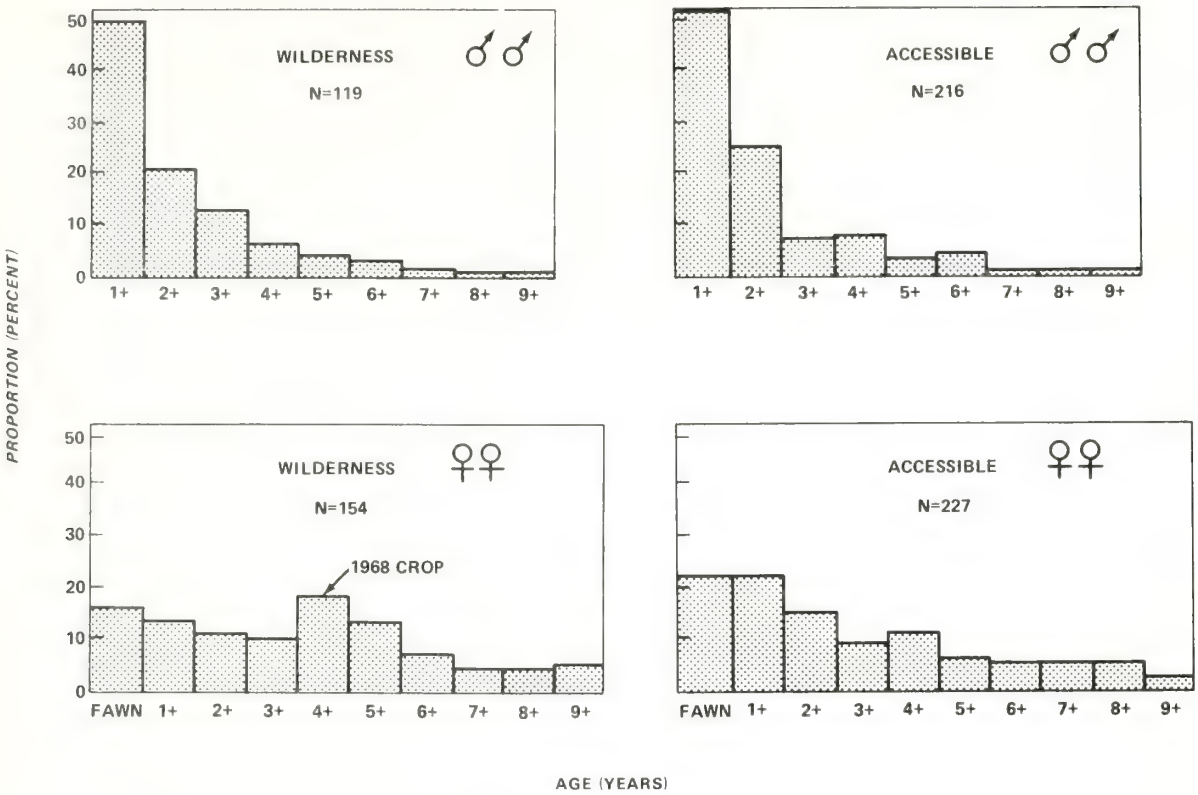

Figure 11. — *Age structures of hunter-killed does in 1972 and 1973 and bucks in 1974 from wilderness and accessible regions of the Superior National Forest (see fig. 2). No fawns are included in 1974 because it was illegal to take them during the bucks-only season.*

Table 3. - *Mean ages of hunter-killed deer in the Superior National Forest*

Years	Area	Including fawns			Excluding fawns[1]	
		Sex	Number	Mean Age	Number	Mean Age
				Years		*Years*
1967, 1968[2]	Wilderness & Accessible	M	269	2.7	215	3.3
1967, 1968[2]	Wilderness & Accessible	F	154	2.4	100	3.5
1972	Wilderness[3]	F	58	4.5	48	5.3
1972	Accessible[4]	F	118	3.3	91	4.1
1973	Wilderness	F	154	3.1	98	4.7
1973	Accessible	F	173	2.6	109	3.8
1974	Wilderness	M	---	---	119	2.6
1974	Accessible	M	---	---	216	2.5

[1]These columns are included because the bucks-only hunting season during 1974 precluded the inclusion of fawns in the sample.

[2]Mech and Frenzel (1971)

[3]Minnesota Department of Natural Resources Deer Kill Block Nos. 23, 24, 25, 26, 38, 39.

[4]Minnesota Department of Natural Resources Deer Kill Block Nos. 14, 15, 22, 37, 50, 51.

1962, 1963). In moose, it appears that such reduced viability persists as individuals grow older, thus predisposing them to wolf predation at an earlier age than usual (Peterson 1974, Peterson and Allen 1974). Furthermore, poor nutrition tends to prevent yearling does from becoming fertile (Verme 1967). Since yearlings usually form the largest age class of potential breeders in a herd, their infertility could have a substantial effect on fawn production.

An additional effect of inadequate nutrition in controlled captivity experiments is the production of a preponderance of male fawns (Verme 1965, 1967, 1969). Thus the surplus of male fawns in our hunter-kill samples from 1955 through 1970 (fig. 10) probably also is attributable to poor nutrition resulting from forest maturation. Surpluses of males can seriously decrease the breeding potential of a deer herd.

Young aspen communities less than 25 years old are considered prime deer habitat in northern Minnesota and the Great Lakes Region. Generally both the quality (Halls and Epps 1969) and the quantity (Halls and Alcaniz 1968) of deer browse decreases with advancing forest succession (Cowan *et al.* 1950). However, the aspen forests of Minnesota are maturing faster than they are being cut or burned. From 1952 to 1972 the percentage of young aspen forests dropped from 65 to 21 (Stone 1966), and the older forests were being succeeded by balsam fir (Buell and Niering 1957), which further closed the canopy. This trend led Urich[8] to conclude that "the decline of deer numbers in northern Minnesota appears to be related to loss of spring, summer and fall habitat due to forest maturity."

The deer decline during the present study, and eventually the complete loss of deer in the Interior Area, was first evident in the most extensive stand of virgin forest in the Superior National Forest, near Little Saganaga Lake. As early as 1936, this region harbored the fewest deer (fig. 3), and Stenlund (1955) wrote: "Deer numbers have remained low [in the virgin forest] for the past 30 years, and there is no reason to believe that they will increase in the future." Thus we conclude that the gradual maturation of the forests of northern Minnesota seriously contributed to the deer decline in the late 1960's.

[8] *Urich, D. L. 1973. Nutrient levels in deer and moose forage in northern Minnesota as related to site characteristics. Unpublished M.S. thesis, University of Minnesota, St. Paul, Minnesota.*

However forest maturation cannot account completely for the precipitous loss of deer and the total demise of the herd in the Interior. Deer numbers dropped even in areas of the Interior that had been extensively logged from 1940 to 1968. Furthermore, all the deer were not lost in most of north-central and northeastern Minnesota despite the trend there in increasing forest maturation. A population averaging up to 15 deer/2.6 km^2 (1 mi^2) still inhabits those regions.

A second important factor contributing to the deer decline in northeastern Minnesota and the entire Great Lakes Region, was the series of severe winters that began in 1964. The mean number of fawns per 100 does in northeastern Minnesota dropped from 104 during 1955 through 1964 to 71 during 1965 through 1973 (table 2). Even in the north-central region, where winters were consistently less extreme although still severe, the drop during the same period was from 112 to 94 fawns per 100 does.

Besides having an adverse effect on fawn production, extreme winters may directly reduce viability and survival of deer (Verme 1968). Such an effect was widely seen in the study area in February and March 1969. The WSI that winter was 190, and the snow accumulation was the deepest on record (Mech and Frenzel 1971). Surplus killing (Kruuk 1972) by wolves was conspicuous and seemed to be related both to the snow conditions and to reduced viability of the deer (Mech and Frenzel 1971). That was the last winter during which large numbers of deer were seen in the Interior and surrounding areas (figs. 5, 6, 7, and 8). Similar surplus killing of moose by wolves was observed for the first time during the same winter on nearby Isle Royale (Peterson and Allen 1974).

The series of extreme winters, combined with the deteriorating deer habitat resulting from forest maturation and succession, no doubt explains the general decline of deer throughout the Great Lakes Region. However, it does not explain why the loss of deer was total in the Interior Area and why the population did not begin to recover in northeastern Minnesota in 1972 as it did in other parts of Minnesota and in Michigan and Wisconsin.

Role of the Wolf

The main difference in deer ecology between northeastern Minnesota and other areas of the Great Lakes

Region was the presence of a high wolf population in northeastern Minnesota. Based on winter predation rates projected year-round, the estimated average annual kill by wolves is the equivalent of about 18 deer per wolf (Mech and Frenzel 1971, Kolenosky 1972). When use of other prey is considered, the annual rate is estimated at 15 deer per wolf (Mech 1971). At one wolf per 26 km^2 (10 mi^2), which approximates the density present in the Interior Area during winter 1967-68 (Mech 1977b), this amounts to an estimated annual kill by wolves of 1.5 deer per 2.6 km^2 (1 mi^2), or about 2.6 kg (5.6 lb) per wolf per day. However, under some conditions during winter, wolves can consume up to twice as much food (Mech 1966, 1977a).

Furthermore, the wolf density in the Interior Area increased to the following percentages above the 1967-68 level: 21 percent in 1968-69, 46 percent in 1969-70, 9 percent in 1970-71, and 11 percent in 1971-72 (Mech 1977b). Assuming a predation rate of one deer per 15 days per wolf, this could have meant an annual kill of as high as 4.5 adult-sized deer per 2.6 km^2 (1 mi^2) in 1969-70.

The deer density in the area during this study was not estimated by any census. Stenlund (1955) considered the average density for the entire Superior National Forest to be 9.0 deer per 2.6 km^2 (1 mi^2) in 1953, but he felt it to be less in most of the Interior.

Assuming a density as high as 9.0 deer per 2.6 km^2 (1 mi^2), a fall ratio of 100 fawns:100 does, and an even ratio of bucks to does, the annual increment to the fall deer population would be 33 percent, or 3.0 deer/2.6 km^2. With the wolf population consuming an estimated 1.5 to 4.5 adult-sized deer/2.6 km^2, these very general figures indicate that even with a relatively high deer density and annual productivity, wolves at the estimated density could consume the equivalent of an entire annual crop of deer each year.

To test the effect of an increasing wolf population interacting with a deer herd producing decreasing numbers of fawns, we applied the actual data to the simple predator-prey model described earlier. The application of the general model (table 4) yields a prediction of a deer herd declining rapidly to zero by 1972 (fig. 12). (The more sophisticated SNOPOP model yielded the same basic population trend, as discussed in Appendix A.)

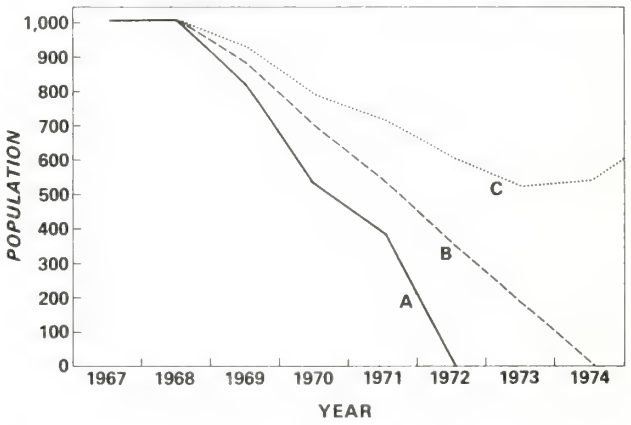

Figure 12. — *Results of model of deer population decline, assuming herd of 1,000 does in 1967 (see table 4). A = result of basic model, applying to the eastern half of the intensive study area (fig. 2); B = result assuming 15 percent less annual kill of deer; C = result assuming 25 percent less annual kill of deer.*

Table 4. — *Basic model of deer decline in the wilderness eastern half of the Superior National Forest, females only*

Year	Fall population of does	Annual increment: Fawns per 1,000 does[1]	Annual increment: Female fawns[2]	Annual increment: Female fawns	Wolf population index[3]	Annual loss: Estimated	Annual loss: Net	New population
			Percent	*Number*				
1967[4]	1,000	850	41	349	1.00	349	0	1,000
1968	1,000	660	36	238	1.21	422	184	816
1969	816	650	43	228	1.46	510	281	535
1970	535	710	36	137	1.09	380	243	292
1971	292	[5]630	[5]41	75	1.11	387	312	0

[1]From table 2. The 1967 figure is the mean of 1963-1967 rates, used to dampen effect of sampling error.

[2]From figure 9.

[3]Derived from Mech (1977b). 1.00 of this index equals 5.7 in figure 2 of Mech (1977b).

[4]The basic assumptions are that the deer population was stable from 1967 to 1968, that 100 percent of the deer mortality in the area was either caused by wolves or utilized by them as carrion, and that the annual loss of deer was proportional to the Wolf Population Index.

[5]Since no figures are available for 1971, the mean for 1968-1972 was used. This mean probably is too high because 1971 was the severest winter on record.

In applying the simple predator-prey model, we made several changes in assumptions to determine the effect that any inaccuracies in our assumptions would have on the final results. One of the most critical assumptions was that the deer population was stable from 1967 to 1968, because future mortality was based entirely on the mortality rate implicit in that assumption. The actual trend from 1967 to 1968 was unknown. However the drop in net production from 90 to 66 fawns per 100 does during those years (table 2) makes it highly probable that the population actually declined. If so, the effect on the model would be to predict depletion of the deer earlier than 1972.

Nevertheless, we tested the assumption that from 1967 to 1968 the deer herd actually increased by 10 percent. The results still predicted depletion, but by 1978 instead of 1972; by 1972 the population would have equalled about 43 percent of the 1968 herd. Furthermore, by using the mean of the fawn:doe ratios from 1963 to 1967 (85 fawns:100 does) for 1967, rather than the actual 1967 ratio (90:100), we dampened the effect any changes in population from 1967 to 1968 might have had.

Another assumption whose effect was tested was that changes in wolf density brought proportional changes in deer mortality, e.g., if wolves increased by 25 percent, so did deer mortality to wolves. To test the effect of inaccuracies in this assumption, we imposed on the model an arbitrary 15-percent decrease in calculated deer mortality for all years after 1967; the result was that the predicted year of depletion was 1975 rather than 1972 (fig. 12). Greater reductions in mortality merely caused later decimation except that reductions of 25 percent or more allowed the population to begin to recover (fig. 12). This recovery trend occurred because in 1973 fawn production returned to pre-decline levels. Thus a 25 percent reduction in annual mortality would preserve enough breeding stock to allow the increased fawn production to more than compensate for the mortality. This point will be discussed later.

In actuality, it appears that rather than deer mortality being reduced proportionally as the wolf population increased after winter 1967-68, such mortality may have increased. Frenzel (1974) found that deer made up a much higher proportion of the wolf's summer diet in the Interior Area in 1968, 1969, 1970, and 1972 (not measured in 1971) than in 1967, as indicated by scat analyses. When this trend was applied to the model, it caused the decline to become steeper and the year of depletion to be earlier than 1972.

The model was also manipulated to see what it would predict if the wolf population had remained stable from winter 1967-68 through 1971-72 instead of increasing, but then had declined as it did from 1971-72 through 1974-75. (A bucks-only deer season precluded obtaining fawn production data in 1974, so we assumed that the increased fawn production found in 1973 also held for 1974.) The result was still depletion, but in 1975 instead of 1972.

Our last manipulations simulated reductions in the wolf population by various constants from year to year. Because of the assumption that changes in wolf populations brought proportional changes in deer mortality, this manipulation is precisely the same as the arbitrary reductions in deer mortality described above. When the wolf population in the model was reduced by 25 percent each year, the deer population eventually began to recover (fig. 12).

All the above simulations were based on a model of the female segment of the deer population because the fawn production data were collected in numbers of fawns per 100 does. Assuming an equal ratio of bucks to does, the population decline for males would be somewhat slower because males constituted a higher percentage of the fawns than did females (fig. 10). Nevertheless, the population would still disappear.

The net result of the various manipulations performed with the model was that, given all the assumptions that we believe reasonable, and the data available, the model always predicted that the deer population in the Interior Area would decline to zero. Generally this would take place by 1972. Even when the assumptions were extended moderately in directions that appear unlikely, the hypothetical deer herd would still become extinct, but a few years later than with the reasonable assumptions.

In actuality, deer were decimated throughout the Interior Area by winter 1972-73, after the "deer void" had enlarged in radius each winter (figs. 5, 6, and 7). By winter 1974-75, it appeared that the rate of expansion of this void had decreased and that the remnant deer population might have begun to stabilize (figs. 7 and 8).

The model demonstrates what might have happened to the wolf-deer system in the Interior Area, and puts the role of the wolf in the deer decline into sharper focus. It suggests the following hypothesis:

1. Wolf numbers were high at a time when production and/or survival of female fawns dropped markedly

because of forest maturation and a series of extreme winters.

2. Winter 1968-69, with a record snow accumulation, allowed surplus killing by wolves and a consequent increase in wolf numbers.

3. During the subsequent severe winters, then, not only did the fawn:doe ratio and percentage of female fawns remain depressed, but the basic breeding population itself was much reduced. Not only were fewer female fawns per 100 does being produced, but there were fewer does to produce them. This doubly-reduced production accelerated the decline.

4. Meanwhile the larger wolf population was exerting increased pressure on a smaller deer herd. The wolves were still killing primarily older animals and vulnerable fawns during winter (fig. 13), but no doubt they were taking much higher proportions of them than usual. Furthermore, less and less fawn recruitment was available to replace the adults killed.

5. The decreased fawn recruitment might have resulted from increased wolf predation on fawns during summer, for the percentage of fawn remains in wolf scats increased from 10 and 15 in 1967 and 1968 to 50 in 1969 and 1970 (Frenzel 1974). However, fall fawn:doe ratios in 1969 and 1970 were no lower than in 1968. Thus the ultimate factor in the poor fawn recruitment may have been the severe preceding winters, with the wolves merely preying on fawns having a poor chance of surviving anyway.

6. By 1972, deer had begun to decline in importance in the wolf's summer diet, and the use of beaver almost tripled (Frenzel 1974), just as Voigt *et al.* (1976) found during the same period in Ontario. In winter 1973-74, the consumption of moose greatly increased[3]. The change to alternate prey probably had the effect of temporarily subsidizing the wolf population and allowing it to remain larger than it could have on deer alone. This use of alternate prey also allowed the wolves to continue to exert unusual pressure on the reduced deer herd.

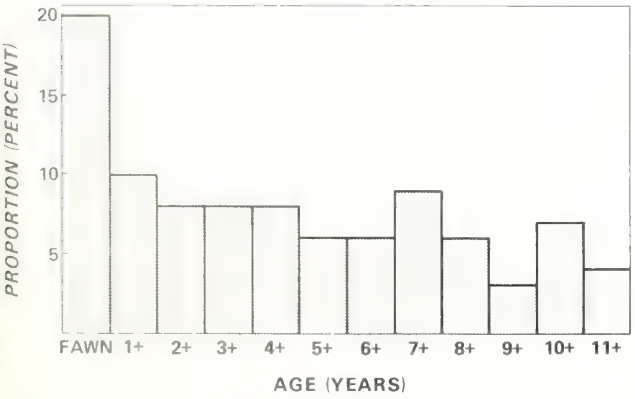

Figure 13. – *Age structure of wolf-killed deer, winters 1970-71 through 1974-75. (No doubt fawns are under-represented here because fawn carcasses are eaten so entirely that usually there are few remains.)*

7. As the prime-age deer that survived the extreme predation pressure grew older and became vulnerable, the wolves depleted their numbers (fig. 13). This fact explains the gradual loss of pockets of wintering deer in the Interior Area (figs. 6 and 7).

8. The tendency of wolves to prey disproportionately on female fawns (Stenlund 1955, Mech and Frenzel 1971) apparently was accentuated (Hoskinson and Mech 1976), thereby further decreasing the proportion of breeders in the deer population. Thus, the males showed a relatively normal age distribution, whereas the females lacked several age classes, at least in the wilderness areas where the effect of wolves was most prevalent (fig. 11). It appears, then, that with a combination of maturing vegetation, severe winters, and intensive wolf predation, it is the female fawns that are the most vulnerable members of a deer herd.

9. As the deer population rapidly diminished, the wolves became increasingly desperate and began concentrating on whatever deer they could find, even if this meant "trespassing" into the territories of other packs (Mech 1972, 1977a, 1977b). This trespassing had several effects: (1) it helped increase the radius of the deer decline outward from the Interior, (2) it put abnormal pressure on the remaining herd outside this area, and (3) it delayed any repopulating of the Interior by deer outside that might otherwise have taken place.

10. Eventually the wolves were still unable to obtain enough food. They began producing fewer young (Mech 1977a, 1977b). The pups they did produce were increasingly underweight (Van Ballenberghe and Mech 1975) and malnourished (Seal *et al.* 1975, Mech 1977a). A disproportionate number of pups were males (Mech 1975).

11. The net result was the extirpation of deer in areas of poorest habitat first. Eventually this decline spread throughout even good habitat. A desperate, declining wolf population (Mech 1977a, 1977b) then continued to exert extreme pressure on the remaining deer around the edges of the "deer void". This pressure helped enlarge the void further.

The deer population model (table 4, fig. 12), then, can be considered to apply earliest to the central Interior Area. In succeeding years, it would apply to an expanding radius around that area, especially as trespasses and migrations of wolves outside the Interior increased wolf density and predation in peripheral areas.

12. However, as the wolf population itself dropped, an estimated 32 percent from 1967-68 to 1974-75, and 55 percent from 1969-70 to 1974-75 (Mech 1977b), its effect on the deer herd diminished. This fact probably explains why the deer decline appeared to be arrested or at least greatly slowed by winter 1974-75 and deer persisted outside the Interior Area.

It is difficult to prove that wolves contributed to the deer decline rather than that they merely took advantage of it. However, several strong pieces of evidence support a hypothesis that wolves did contribute to the decline. First, although reduction of the fawn:doe ratio probably resulted from forest maturation and extreme winters, reduction of the *number* of adult does, i.e., the breeding population, is attributable to wolves. With an adequate fawn crop each year to replace the old deer killed by wolves, this loss would be of no great significance. However, when annual fawn recruitment is poor, wolves must resort to killing a higher proportion of older potential breeders which are not replaced. This doubly disastrous effect accelerates the decline. Without wolves, these older deer could live longer, and despite the loss of several fawn crops, the population could persist. Then when favorable weather again prevailed, the breeders could produce a few good fawn crops and thereby help the herd recover.

Second, comparison of the doe age distributions for the wilderness versus the accessible area indicates that the loss of the 1969-72 age classes was much more extreme in the wilderness area where wolf predation was strongest (fig. 11).

As mentioned earlier, wolves were killed much more often by humans in the accessible area thus reducing wolf predation, there. The deer age-structure sample from that area was basically normal. The sample probably represented primarily deer harvested around well used roads, farms, and other areas less affected by wolves. This region still has a remnant deer herd.

Third, wolves are known to prey disproportionately on female fawns and adult males, as discussed earlier, and comparison of the age structures of the doe and buck samples reflect this predation pattern. In the sample of does taken in 1972 and 1973 in the wilderness, the largest age class was that of 1968 (fig. 11). This age class itself was abnormally low because of the reduced production of fawns that year and the high loss of fawns the following winter (Mech and Frenzel 1971). Despite this fact, the 1969, 1970, and 1972 classes were even lower. In 1975, the 1968 class was 7 years old. Inasmuch as deer vulnerability to wolf predation increases markedly after 5 years of age (Pimlott *et al.* 1969, Mech and Frenzel 1971), many of these deer probably were dead by 1975. Meanwhile, female members of the 1969-72 crops were extremely scarce.

The age structure of the males indicated a high turnover of adult bucks, as evidenced by the relative youth of this sample compared both with the does of about the same period (fig. 11) and with the bucks of 1967 and 1968, before the decline (table 4).

Fourth, the deer herds in Michigan and Wisconsin, which underwent similar declines after the same severe winters, were well on their way to recovery by 1975—unlike those in the study area.

Fifth, a high percentage of the deer that remained adjacent to the Interior lived in narrow strips along the outer edges of wolf pack territories. This distribution of deer persisted both in summer and winter, even though summer and winter ranges were sometimes separated by more than 40 km (25 mi) (Hoskinson and Mech 1976,[1]). Wolf packs tend to kill deer along their territory edges after they have depleted the supply elsewhere in their territory and they become desperate (Mech 1977a). Many of the remaining deer living along territory edges are very old (Hoskinson and Mech 1976), demonstrating that animals that did find an area relatively secure from wolves survived longer. In the Interior Area, however, even deer populations living along territory edges were depleted.

The above facts strongly lead to the conclusion that if wolves had not inhabited the Interior of the Superior National Forest, the deer herd would not have disappeared there, the decline would not have been so drastic in the surrounding area, and any tendency for the deer population to recover would not take so long. In fact, one of the trials with the predator-prey model suggests that if the wolf population had been 25 percent lower each year, beginning in 1968, the deer population would have begun to recover by 1973 (fig. 12), as herds did elsewhere.

The conclusion that wolves were one of the main causes of the deer decline in the Superior National Forest will seem trite to many laymen. Certain local residents and many deer hunters have long maintained that wolves were "killing off all our deer". However, we believe that this paper is the first documentation of such a conclusion. Most of the literature on wolf-prey relations has shown that wolves usually do not deplete

their prey populations (Murie 1944, Stenlund 1955, Mech 1966, 1970, Pimlott *et al.* 1969, Kolenosky 1972). Furthermore, logic dictates that if a predator depletes its prey resource over a large enough area, the predator-prey system cannot persist.

The question of the effect of wolf predation on deer populations has been considered by Stenlund (1955), Pimlott (1967), and Mech (1970). However, none of these authors addressed the question of whether wolves could deplete their prey population. Rather, all discussed the ability of wolves to control their prey, and all dealt with more deer per wolf than existed in our study area during the deer decline. Mech (1971) also considered the possible role of the wolf as a competitor with human hunters in accessible areas, but he too assumed a greater ratio of deer per wolf, as is usually the case.

Both Pimlott (1967) and Mech (1970) emphasized that the greatest limiting effect of wolves probably would be through predation on young animals. However, during our study it appeared that predation on old animals was also extremely important in that it reduced the breeding population while there was insufficient fawn recruitment to replace it (fig. 13).

Conceivably the drop in the fawn:doe ratio also was attributable to wolves. However, because this decrease coincided with a series of severe winters and also took place in relatively wolf-free areas (fig. 9), the wolf's role in the fawn crop reduction perhaps was incidental. It is also conjectural how much winter wolf predation on fawns was facilitated by the severe weather during the previous year, when the fawns were fetuses, or during the fawns' first winter. Nevertheless, the apparent predisposition of wolves to take female fawns, during winter at least, and the striking scarcity of female members of the 1969 through 1972 age classes in the wilderness area (fig. 11), suggest the important effect of wolves in fawn predation also.

Because this study describes a situation contrary to most other reports, it is important to emphasize the peculiar combination of circumstances that allowed the present situation to occur. It seems safe to speculate that if the vegetation in the study area were not passing its prime as deer habitat, the mere combination of severe winters and wolf predation would not have had such an extreme result. Evidence for this contention is the fact that deer first disappeared from the region of poorest habitat—the virgin forest. No doubt better habitat would have supported a higher deer density with greater productivity. Then even with severe winters and intensive wolf predation, a larger base population would have been available to resist depletion and to begin recovery.

Or even with maturing vegetation and gradually declining productivity, plus substantial wolf predation, the deer herd probably would not have dropped so precipitously if the series of winters had not been so severe. The severe winters apparently reduced deer productivity far more drastically than the declining habitat, in addition to decreasing the general survivability of deer and increasing deer vulnerability to wolves.

From this analysis, and from the fact that deer herds so seldom disappear, we can conclude that deer populations are remarkably resilient. Only when such important factors as declining habitat, inclement weather, and intensive predation are combined for several consecutive years are local herds unable to survive. It seems significant that the only other report we can find of wolves seriously reducing their prey populations also involved the same combination of detrimental circumstances (Rausch and Hinman 1977).

Future of the Wolf-Deer System

If the disappearance of deer continues to spread throughout the Superior National Forest and northeastern Minnesota, the wolf population there must decline, just as it has already in the Interior Area (Mech 1977a, 1977b). Nevertheless, wolves will be able to survive on moose, supplemented in spring, summer, and fall by beavers, although a much lower wolf density can be expected.

However, there are some promising signs that the deer population may now be holding its own or may even be starting to recover in the study area. After the relatively mild winter of 1972 to 1973, the fawn:doe ratio in Lake and Cook Counties increased to 85, and 52 percent of the fawns were females, the highest ratios for 6 years. That was the last year in which data on such ratios could be obtained because of the bucks-only hunting season, but records of three sets of fawn triplets in the study area during summer 1974 may indicate another year of high production of fawns.

In addition, two of the heaviest fawns on record were live-trapped in the study area in 1973 (Hoskinson and Mech 1976).

Blood samples taken from 1973 through 1976 from 44 deer in the central and eastern Superior National Forest indicated they were in moderately good to excellent condition (Hoskinson and Mech 1976[9]).

The wolf population also declined substantially (Mech 1977b), which reduced the predation pressure. The survivability of the deer remaining in 1973 and 1974 was much higher than in previous years (Hoskinson and Mech 1976). A few deer apparently even began to repopulate part of the Interior Area in winter by 1974-75, although some ended up as kills (fig. 7).

On the negative side, the wolves' resistance to decline, and their ability to respond to any local or temporary availability of prey by an increase in numbers, is considerable (Mech 1977b). This ability could hinder the deer population recovery. Furthermore, the future of the deer herd also depends greatly on the vagaries of winter weather during the next few years.

Of greatest ultimate importance, of course, is the habitat problem. Without considerable increase in logging and/or fires throughout the Superior National Forest, the long-range outlook for deer is dim. Moreover, any prolonged diminution in the deer herd will very probably result in reduced wolf numbers.

Authors' Note: The wolf-deer models described in this bulletin should not be confused with the wolf-deer model publicized in late 1976 in the popular press (Schara 1976). The models, data bases, and conclusions presented herein apply only to the areas and periods described and should not be extended without sufficient corroborating data.

[9] *Seal, U. S. Manuscript in preparation at U.S. Veterans Administration Hospital, Twin Cities, Minnesota.*

APPENDIX A

The Minnesota Department of Natural Resources deer population management model (SNOPOP) was applied by the junior author to the data available for the deer and wolf population of Department of Natural Resources Grid Blocks 23-26, 38, and 39 (fig. 2) from 1971 to 1976. The model assumes an average deer density of 2.3 deer per km^2 (6 deer/1 mi^2) and a predation rate of 15 to 20 deer per wolf per year. It also uses deer age structure as indicated by the hunter kill, productivity as indicated by fetus counts of road-killed deer, and direct winter kill based on actual mortality rates found in an adjacent area and correlated with the WSI.

The model indicates that without wolf predation the deer herd would have declined very little by 1976 but that with the known wolf densities the deer population would drop to less than 0.4 deer/km^2 (1/mi^2) (fig. 14).

SNOPOP is considerably more sophisticated than the simple predator prey model presented in the text (table 4, fig. 12), but it again points out the effects of wolf predation and severe winters on the deer population of northeastern Minnesota.

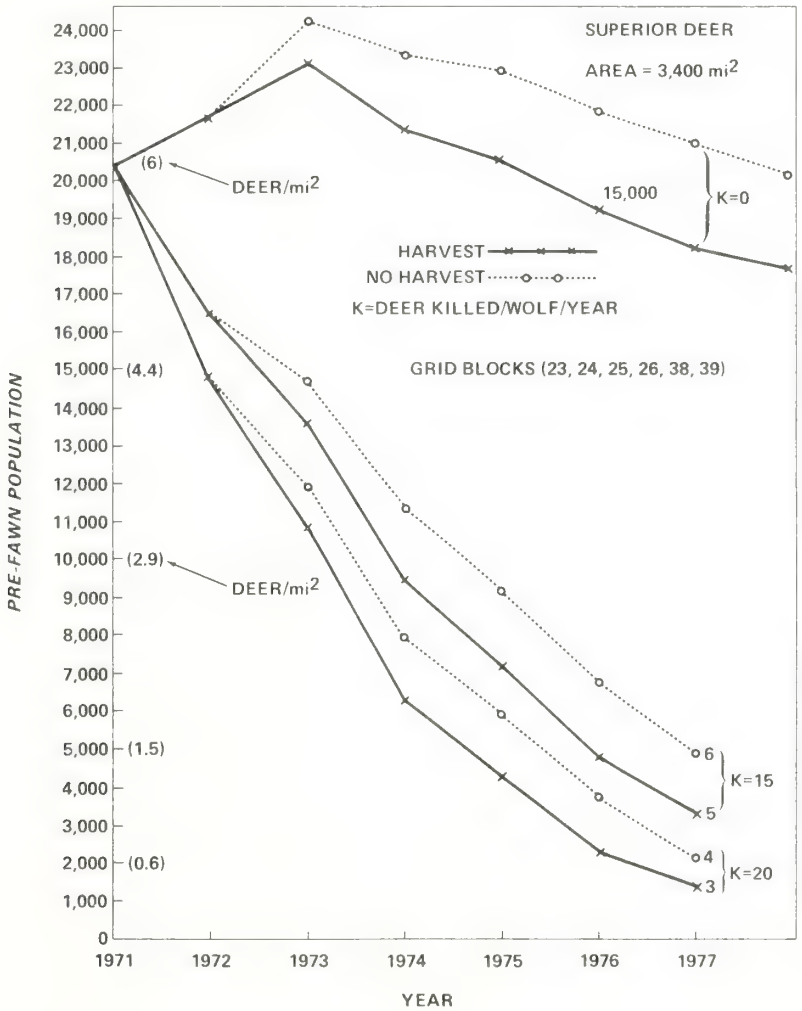

Figure 14. — *Minnesota Department of Natural Resources "SNOPOP" model of the northeastern Minnesota deer population used by the junior author to test the effect of intensive wolf predation during a period of high winter kill of deer.*

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OXFORD: 149.74 *Canis lupus*:149.6 CERVID. KEY WORDS: predation, prey, Minnesota, winter severity.

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Missouri Ozarks

ul S. Johnson

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1977

PREDICTING OAK STUMP SPROUTING AND SPROUT DEVELOPMENT IN THE MISSOURI OZARKS

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Columbia, Missouri

APPLICATION

Although much of the oak regeneration following harvest cutting results from advance reproduction, oak sprouts originating after cutting from newly cut stumps are also valuable in reproducing oak stands. Thus, prediction of stump sprouting and sprout development is an important part of evaluating the total oak regeneration potential before final harvest cutting in oak-hickory stands (Sander *et al.* 1976).

This report provides a way to estimate the proportion of stumps that will have codominant-or-larger sprouts 5 years after clearcutting. Tables for predicting these proportions were prepared for white oak (*Quercus alba* L.) (table 1), black oak (*Q. velutina* Lam.) (table 2), and for scarlet oak (*Q. coccinea* Muenchh.), post oak, (*Q. stellata* Wang.), and blackjack oak (*Q. marilandica* Muenchh.) (table 3).

The proportions given are for stumps with codominant-or-larger stems (9.6 feet tall or taller) because smaller sprouts are unlikely to contribute significantly to future stand stocking. For black and white oaks, proportions are presented for combinations of parent-tree age and site index for a range of tree diameters (table 1 and 2); for the other species, tree age and site index were not obtainable, so average proportions are presented by tree diameters only (table 3).

HOW TO USE THE TABLES

To calculate the potential for oak stump sprouts before final harvest cutting, you need a sample inventory of diameters of overstory oaks. The inventory routinely used in silvicultural stand examinations to estimate overstory basal area and number of trees per acre will satisfactorily meet this need provided that all oaks 1.6 inches d.b.h. and larger are included in the number of trees per acre (Roach and Gingrich 1968).

Multiply the number of oaks (per unit area) in each diameter or diameter-age class by the appropriate proportion in tables 1, 2, or 3 to get estimates of the number of codominant-or-larger stump sprouts that are likely to be present 5 years after clearcutting.[1]

When you use tables 1 and 2, it will be necessary to determine mean age of oaks from trees selected over the range of diameters present. In true even-aged stands, small diameter trees will be approximately the same age as larger diameter trees. However, if all or most of the smaller diameter oaks are of a different age class, the overstory diameter tally can be divided into two (or more) age classes, and appropriate proportions then applied to the diameter distribution of each age class. For exact determination of proportions for diameter, age, and site values not given in tables 1, 2, or 3, equations for calculating proportions are given in the Documentation section.

[1] *These 5th-year estimates of numbers of stump sprouts per acre can be multiplied by 0.89 to obtain expected 20th-year numbers of sprouts. This number can be compared to the number of stump sprouts required for adequate regeneration given in "A guide for evaluating the adequacy of oak advance reproduction" (Sander* et al. *1976).*

Table 1. — *Proportion of white oak stumps that are expected to produce a codominant-or-larger[1] sprout stem 5 years after cutting, by tree diameter, age, and site index*

D.b.h.	Tree age (years)				
	40	60	80	100	120
Inches	*Proportion*				
SITE INDEX 50					
2	0.69	0.44	--	--	--
4	.57	.35	0.18	--	--
6	.43	.26	.14	0.07	--
8	.31	.19	.10	.05	0.03
10	.21	.13	.08	.04	.02
12	.15	.10	.06	.04	.02
14	--	.07	.05	.03	.02
16	--	.05	.04	.03	.02
18	--	.04	.03	.02	.02
20	--	--	.02	.02	.02
22	--	--	.02	.02	.02
24	--	--	--	.02	.02
26	--	--	--	--	.02
SITE INDEX 60					
2	0.79	0.58	--	--	--
4	.68	.48	0.28	--	--
6	.54	.37	.22	0.11	--
8	.41	.28	.17	.09	0.05
10	.30	.21	.13	.07	.04
12	.22	.15	.10	.06	.04
14	--	.11	.08	.05	.04
16	--	.08	.06	.05	.03
18	--	.06	.05	.04	.03
20	--	--	.04	.04	.03
22	--	--	.03	.03	.03
24	--	--	--	.03	.03
26	--	--	---	--	.03
SITE INDEX 70					
2	0.88	0.73	--	--	--
4	.79	.63	0.42	--	--
6	.65	.51	.34	0.19	--
8	.52	.40	.27	.16	0.09
10	.41	.31	.21	.13	.08
12	.32	.24	.17	.11	.07
14	--	.18	.14	.10	.07
16	--	.14	.11	.08	.06
18	--	.11	.09	.07	.06
20	--	--	.07	.06	.06
22	--	--	.06	.06	.05
24	--	--	--	.05	.05
26	--	--	--	--	.05

[1]Trees 9.6 feet in height or taller.

Table 2. — *Proportion of black oak stumps that are expected to produce a codominant-or-larger[1] sprout stem 5 years after cutting, by tree diameter, age, and site index*

D.b.h.	Tree age (years)					
	40	60	80	100	120	140
Inches	*Proportion*					
SITE INDEX 50						
2	0.53	0.52	--	--	--	--
4	.46	.44	0.42	--	--	--
6	.33	.31	.28	0.26	--	--
8	.23	.20	.18	.16	0.14	--
10	.16	.14	.12	.10	.09	--
12	.12	.10	.09	.07	.05	0.04
14	--	.08	.06	.05	.04	.03
16	--	.06	.05	.03	.02	.02
18	--	.05	.04	.03	.02	.01
20	--	--	.03	.02	.01	.01
22	--	--	.02	.01	.01	0
24	--	--	--	.01	.01	0
26	--	--	--	--	0	0
SITE INDEX 60						
2	0.64	0.63	--	--	--	--
4	.57	.54	0.52	--	--	--
6	.41	.38	.36	0.33	--	--
8	.28	.26	.24	.21	0.19	--
10	.21	.18	.16	.14	.12	--
12	.16	.14	.12	.10	.08	0.06
14	--	.11	.09	.07	.05	.04
16	--	.09	.07	.05	.04	.03
18	--	.07	.05	.04	.03	.02
20	--	--	.04	.03	.02	.01
22	--	--	.03	.02	.01	.01
24	--	--	--	.02	.01	.01
26	--	--	--	--	.01	0
SITE INDEX 70						
2	0.76	0.75	--	--	--	--
4	.67	.65	0.63	--	--	--
6	.49	.47	.45	0.42	--	--
8	.34	.32	.30	.28	0.25	--
10	.25	.23	.21.	.19	.17	--
12	.20	.18	.16	.13	.11	0.09
14	--	.14	.12	.10	.08	.06
16	--	.11	.09	.07	.06	.04
18	--	.10	.07	.06	.04	.03
20	--	--	.06	.04	.03	.02
22	--	--	.05	.03	.02	.01
24	--	--	--	.03	.02	.01
26	--	--	--	--	.01	.01

[1]Trees 9.6 feet in height or taller.

Table 3. — *Proportion of scarlet, post, and blackjack oaks that are expected to produce a codominant-or-larger*[1] *sprout stem 5 years after cutting, by tree diameter*

D.b.h.	Scarlet oak	Blackjack oak	Post oak
Inches	- - - *Proportion* - - -		
2	--	0.84	0.91
4	0.52	.64	.80
6	·82	.36	.54
8	·85	.20	.32
10	·77	.11	.17
12	.63	.06	.07
14	.28	.03	.02
16	.26	.02	0
18	.14	.01	--
20	.08	0	--
22	.07	0	--

[1]Trees 9.6 feet in height or taller.

DOCUMENTATION

THE BASIC DATA

The 1,546 stumps measured in the study were located in four areas on the Mark Twain National Forest in southern Missouri. Site indices for upland oaks on study areas ranged from 35 to 85, based on Schnur's (1937) curves. Scarlet oaks were restricted to a site index range of 50 to 65 and most post and blackjack oaks were within the range of 35 to 60; about three-fourths of black and white oaks were within the site index range of 50 to 70.

All black and white oaks and approximately two-thirds of the scarlet, post, and blackjack oaks that were sampled were cut trees. Time of cutting ranged from late January through late October, but no trees were cut during August. The remaining one-third of the post, scarlet, and blackjack oaks were standing trees located in portions of two stands completely killed by wildfires in late March and late April 1963. Because burning destroyed the bark on most of the fire-killed trees, the only diameter measurement made on all trees was stump diameter inside bark; measurements were made to the nearest inch (2.5 cm), 6 to 12 inches (15.2 to 30.5 cm) above the ground. For all but blackjack oak, diameters inside bark ranged from 3 inches (7.6 cm) to 30 inches (76.2 cm) or more; the maximum diameter of blackjack oak was 18 inches (45.7 cm) (table 4).

For all species, measurements were also made of: (1) height of the tallest stem per sprout clump to the nearest foot (30.5 cm) after one, three, and five growing seasons and (2) number of live stems per clump after one, three, and five growing seasons. For black and white oaks additional measurements were made of: (1) tree age at stump height, (2) site index, (3) bark thickness to the nearest 0.1 inch (2.5 mm), (4) the last 10 years' radial growth at stump height to the nearest 0.1 inch, and (5) the week of the year (beginning January 1) trees were cut or killed. For white oak, week of cutting ranged from week 3 (January 15 to 21) to week 43 (October 21 to 27) with 22 percent of trees cut in the dormant season. For black oak, week of cutting ranged from week 10 (March 4 to 10) to week 43, with 45 percent of trees in the dormant season. Ages of black and white oaks ranged from less than 30 years to over 200 years, with most (92 percent) between 40 and 140 years.

GENERAL SPROUTING RELATIONS

The percent of stumps with sprouts at the end of the first growing season ranged from 21 percent for white oak to 66 percent for scarlet oak (table 5). However, among stumps with living sprouts after the first growing season, only 50 percent of black oak and 61 percent of post oak stumps had living sprouts after five growing seasons; survival for the other species ranged from 86 to 89 percent.

Scarlet and white oak sprouts were the tallest after 5 years; the heights of dominant sprouts averaged 14 feet (4.3 m) for both species (table 5). Dominant-sprout

Table 4. *Distribution of stumps sampled by species and diameter class*

Species	Stump diameter class (inches, inside bark)				
	≤10	11 to 15	16 to 20	21+	Total
	Number of stumps				
White oak	84	89	155	28	356
(Age range-years)	(28-125)	(48-140)	(67-175)	(90-200)	
(Site index range-feet)	(55-70)	(36-75)	(36-75)	(36-75)	
Black oak	31	86	132	45	294
(Age range-years)	(25-75)	(50-130)	(46-163)	(75-225)	
(Site index-feet)	(48-65)	(36-75)	(36-80)	(36-75)	
Scarlet oak	88	96	89	18	291
Post oak	81	87	159	45	372
Blackjack oak	154	65	14	0	233

Table 5. — *Percent of stumps with living sprouts and mean heights of sprouts*[1] *by species and years after cutting*

Species	Growing seasons after cutting					
	1		3		5	
	Mean height	Stumps with living sprouts	Mean height	Stumps with living sprouts	Mean height	Stumps with living sprouts
	(*Feet*)	(*Percent*)	(*Feet*)	(*Percent*)	(*Feet*)	(*Percent*)
White oak	2.3	21	7.2	20	13.8	18
Black oak	2.4	30	6.7	19	11.4	15
Scarlet oak	3.8	66	9.5	60	14.0	58
Post oak	2.5	28	6.4	20	10.8	17
Blackjack oak	3.2	46	7.2	43	10.0	41

[1]Means are based on height of dominant stem in each clump.

heights for the other species averaged 10 to 11 feet (3.0 to 3.3 m) tall. For all species, the 5th year height of the dominant sprout was significantly but negatively correlated with stump diameter inside bark (table 6). For black oak, dominant-sprout height at age 5 was significantly—but weakly—correlated with site index ($r = 0.37$, $p < 0.05$).

Number of living stems per clump for all species declined rapidly over the 5-year study period. Average numbers of stems per clump ranged from 7 to 9 at the end of the first growing season for all but scarlet oak, which averaged about 12 stems per clump. However, by the end of the fifth growing season, all species averaged 2 to 3 stems per clump. Although correlations were generally weak, the number of living stems after five growing seasons was significantly and negatively correlated with stump diameter inside bark for all species (table 6). In addition, the number of living stems per clump after 5 years was significantly and positively correlated with the 5th-year height of dominant sprouts for all species; correlation coefficients ranged from 0.28 for scarlet oak to 0.80 for black oak (table 6).

SPROUTING PROBABILITIES

A regression procedure for estimating event probabilities was used to estimate the probability (P_1) that a stump will have at least one live sprout at the end of the first growing season after cutting (or death of the parent tree caused by fire) (Hamilton 1974). For black and white oaks, P_1 was predicted from three factors: (1) stump diameter outside bark, (2) age of parent tree, and (3) site index. After variation attributable to the latter factors were accounted for, other measured factors (bark thickness, 10-year radial growth, and week cut) showed no statistically significant relation to P_1. Final predicting equations were selected from more than 100 equations calculated for each species. The relations between P_1 and the first three factors were the same for both species; P_1 decreased as stump diameter and age increased, and increased as site index increased (figs. 1 and 2). For black oak, values of P_1 for site index 70 ranged from 0.75 for 40-year-old trees 3 inches (7.6 cm) in stump diameter to 0.08 for 120-year-old trees 30 inches (76.2 cm) in diameter; for white oak, P_1 ranged from 0.88 to 0.12 for the same combination of factor values.

Table 6. — *Simple correlation coefficients (r) between selected variables for oak stumps that had living sprouts at the end of the first growing season*

Variable	Dominant sprout height after 5 growing seasons					Number of living stems per clump after 5 growing seasons				
	Oak species					Oak species				
	Black	White	Scarlet	Post	Blackjack	Black	White	Scarlet	Post	Blackjack
Stump diameter (inside bark)	[1]-0.55**	-0.46**	-0.18*	-0.70**	-0.34**	-0.64**	-0.23**	-0.47**	-0.38**	-0.23*
Site index	0.37**	ns	([2])	([2])	([2])	0.28**	-0.24*	([2])	([2])	([2])
Dominant-sprout height after 5 growing seasons	--	--	--	--	--	0.80**	0.53**	0.28**	0.66**	0.56**
Number of observations	87	76	192	106	107	87	76	192	106	107

[1]Significance level of r: ** = 0.01; * = 0.05; ns = nonsignificant.
[2]Site index not measured.

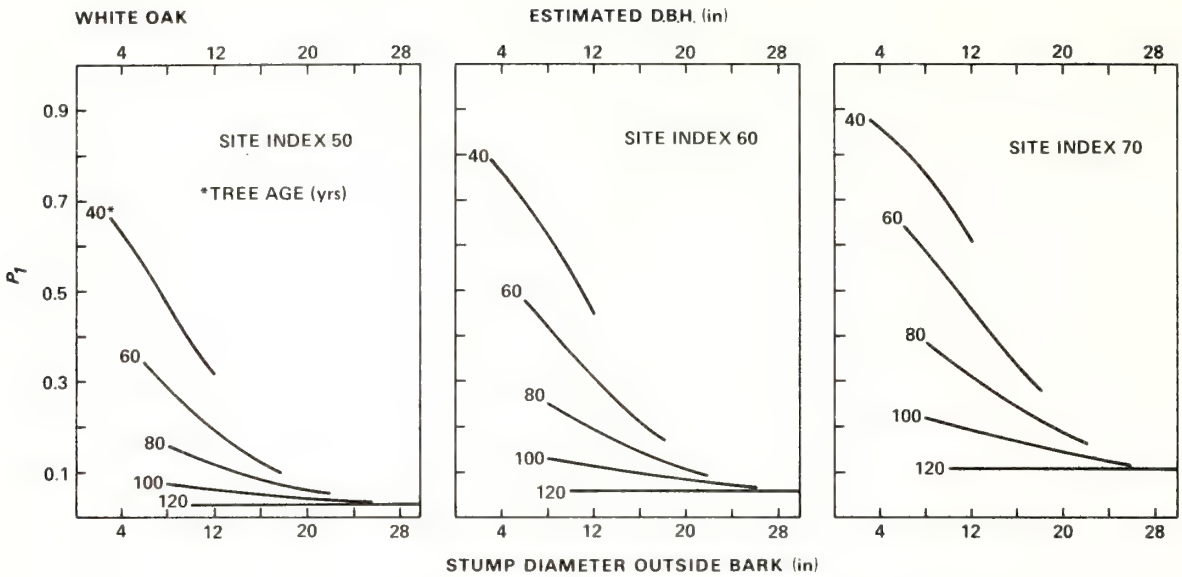

Figure 1. – *Estimated probabilities (P_1) for white oak stumps in relation to tree diameter, age, and site index. (P_1 = probability that a stump will have at least one living sprout at the end of the first growing season after cutting; regression equations and goodness-of-fit statistics are given in table 7. D.b.h. was estimated from stump diameter (outside bark) based on the table for hardwoods from Horn and Keller (1957).)*

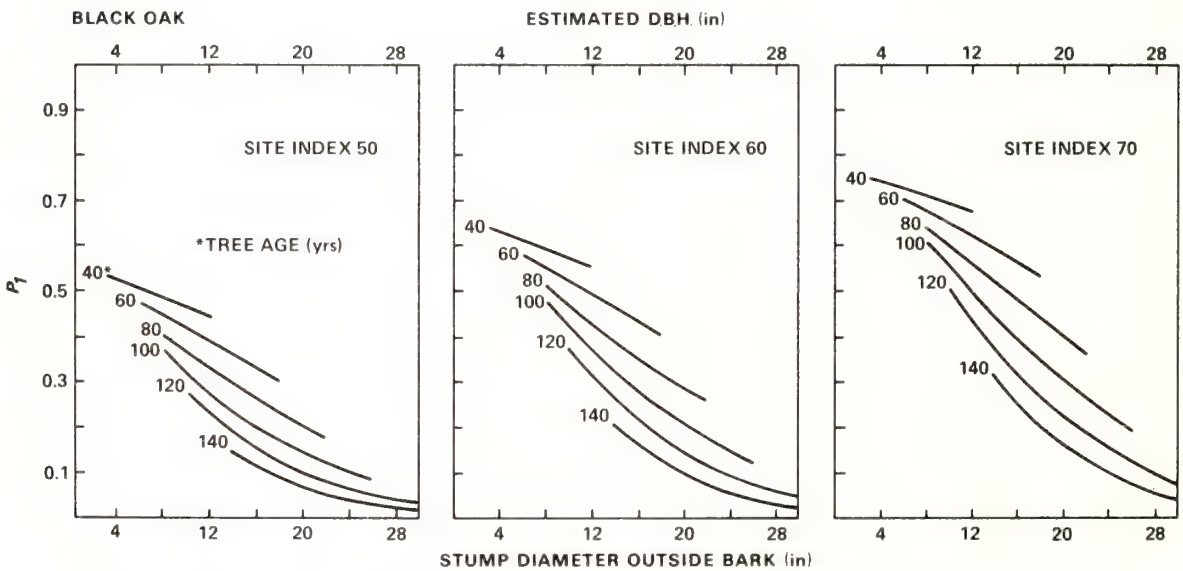

Figure 2. – *Estimated probabilities (P_1) for black oak stumps in relation to tree diameter, age, and site index. (P_1 = probability that a stump will have at least one living sprout at the end of the first growing season after cutting; regression equations and goodness-of-fit statistics are given in table 7. D.b.h. was estimated from stump diameter (outside bark) based on the table for hardwoods from Horn and Keller (1957).)*

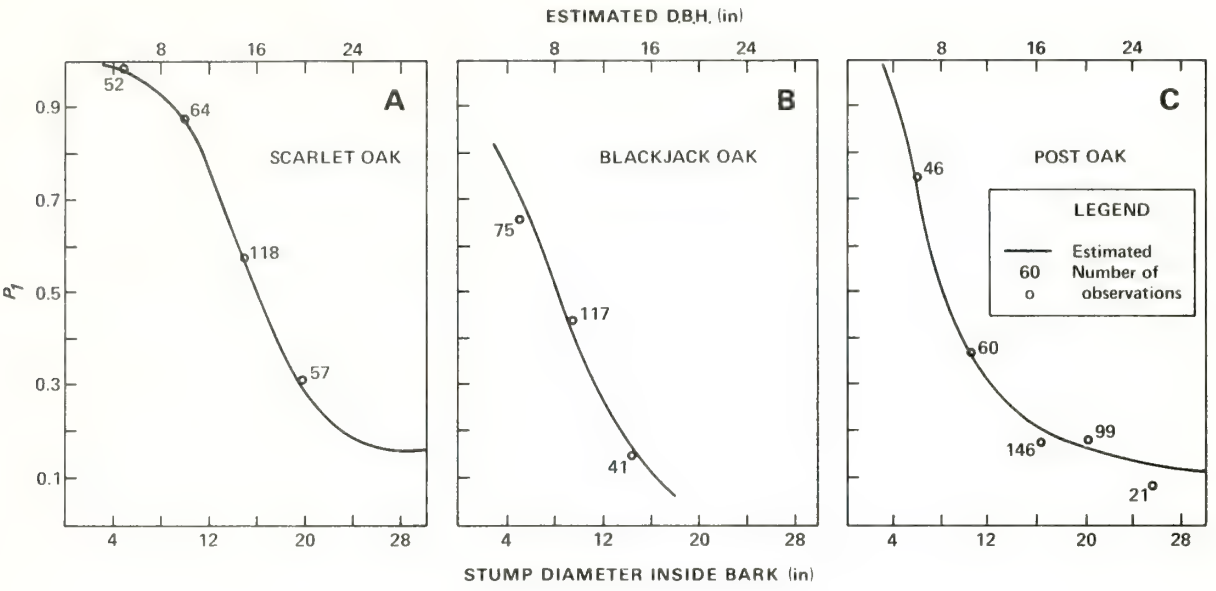

Figure 3. — *Estimated probabilities (P_1) for scarlet, blackjack, and post oak in relation to tree diameter. (P_1 = probability that a stump will have at least one living sprout at the end of the first growing season after cutting; regression equations and goodness-of-fit statistics are given in table 7. Observed values are means for diameter classes that include at least 10 observations per class. D.b.h. was estimated from stump diameter outside bark (d.o.b.) based on the table for hardwoods from Horn and Keller (1957); d.o.b. was estimated by regression of bark-thickness on stump diameter (inside bark) using data for black and white oaks.)*

Table 7. — *Regression coefficients for P_1 equations represented by figures 1, 2, and 3*[1]

Species	B_0	Independent variables[2] X_1	X_2	X_3	X_4	X_5	X_6	Number of observations
Black oak	[3]-0.7853[ns]					-1.0160×10^{-3}**	4.1528×10^{-4}**	294
White oak	2.2330*	-0.2525**			-0.0511**	2.1145×10^{-3}**	5.1120×10^{-4}*	356
Scarlet oak	6.9053**	-0.5948**	1.0239*					291
Post oak	-2.8058**			22.6839**				372
Blackjack oak	2.3656**	-0.2781**						233

[1]Equations are of the form: $P_1 = \{1 + \exp[-(B_0 + B_1X_1 + \ldots B_nX_n)]\}^{-1}$, where P_1 is the probability that a stump has a living sprout at the end of the first growing season after cutting.

[2]X_1 = Stump diameter (inches) = DIAM (outisde bark for black and white oaks; inside bark for other species); X_2 = $DIAM^2/100$; X_3 = 1/DIAM; X_4 = Age of tree in years at stump height = AGE; X_5 = DIAM x AGE; and X_6 = $(\text{Site index})^2$.

[3]Significance levels are based on "t" tests (H_0 : B = 0) and are: * = 0.05, ** = 0.01, ns = nonsignificant; $p < 0.01$ for all regression F tests. Goodness-of-fit was also tested by chi-square for differences between observed and predicted numbers of stumps with living sprouts among probability intervals of width 0.05; all chi-square values were nonsignificant at the 0.05 level. Goodness-of-fit was based on the above relation because the customary measure, the error mean square, is not appropriate when the dependent variable is dichotomous.

A significantly larger proportion of both black and white oaks cut during the dormant season sprouted than did those cut during the growing season. However, black and white oaks cut during the dormant season had a smaller mean diameter than those cut during the growing season, thus confounding analysis of effects attributable to diameter and week of cutting.

For scarlet, blackjack, and post oak, P_1 was predicted from stump diameter inside bark (fig. 3). For scarlet oak, P_1 declined from 0.99 for 3-inch stumps to 0.15 for 30-inch (76.2 cm) stumps; post oak similarly declined from 0.99 to 0.11 over the same range of stump diameters. For a given diameter, blackjack oak tended to sprout less frequently than either scarlet or post oak, with P_1 ranging from 0.82 for 3-inch (7.6 cm) stumps to 0.07 for 18-inch (45.7 cm) stumps.

Sprouting was significantly greater for fire-killed scarlet, post, and blackjack oaks than for felled live trees (unburned) based on chi-square analyses at the 0.05 level. However, these differences were at least partially related to stump diameters, which on the average were smaller for fire-killed trees than unburned cut trees. When differences due to stump diameter were removed, significant differences in proportion of burned versus unburned stumps that sprouted occurred only in scarlet oak and within the diameter range of 10 to 15 inches (25.4 to 38.1 cm); sprouting was 82 percent for fire-killed trees and 55 percent for unburned cut trees. Thus, there is only slight evidence that burning *per se* increased the proportion of stumps that sprouted.

SPROUT DEVELOPMENT PROBABILITIES

The regression procedure for estimating P_1 was also used to estimate the probability (P_2) that a stump with a living sprout at the end of the first growing season after cutting (or killing of the parent tree by fire) will have a live sprout that is codominant or larger[2] after five growing seasons. P_2 was predictable from stump diameter for all five species (fig. 4). For all but scarlet oak, estimates of P_2 were highest (0.90 or greater) for 3-inch (7.6 cm) stumps, and declined to lower values at larger stump diameters. For scarlet oak, the highest value of P_2 (0.92) was attained at a stump diameter of 9 inches (22.9 cm); P_2 declined as diameter increased or decreased from that size (fig. 4c).

REPLACEMENT PROBABILITIES

Pre-harvest estimation of the potential contribution of stump sprouts to future stand composition and stocking after harvest cutting was facilitated by multiplying P_1 (sprouting) by P_2 (sprout development). Resultant values can be defined as replacement probabilities, i.e., the estimated proportion of trees that will be replaced, 5 years after cutting, by at least one living codominant-or-larger sprout stem. Replacement probabilities (expected proportions) are presented in tables 1, 2, and 3. These values generally parallel trends for P_1, but are adjusted for expected survival and growth of sprouts to age 5.

DISCUSSION

Other investigators have previously observed that the proportion of oaks that sprout decreases as the diameter of the parent tree increases; studies have included black, white, and scarlet oaks (Roth and Hepting 1943), blackjack oak (Clark and Liming 1953), northern red oak (*Quercus rubra* L.) (Johnson 1975), and English oak (*Q. pedunculata* (sic *Q. robur* L.)) (Kharitonovich 1937). Clark and Liming (1953) also found that in 1- to 12-inch (2.5 to 30.5 cm) d.b.h. blackjack oak, mortality of sprouts increased as stump diameter increased, thus paralleling estimates of P_2 in the present study. An exception to this pattern was scarlet oak, for which values of P_2 increased with increasing diameter up to 7 inches (17.8 cm) d.b.h. (fig. 4c). The reason for this departure from the apparent norm is not known, but may be related to the unknown age distribution of the scarlet oaks sampled.

Other investigators have also reported a decline in oak stump sprouting as trees age (e.g., Roth and Sleeth 1939, and Rogers and Rogers 1959). However, age-dependent estimates of sprouting capacity have usually been averaged over unspecified variation in parent tree diameter,

[2] *Codominant-or-larger was defined as a stem 9.6 feet (2.9 m) tall or taller, and refers to the position of the dominant sprout (tallest per stump) in the stand as a whole. This minimum height was arbitrarily selected as 80 percent of the unweighted mean height (12 feet (3.7 m)) of 5-year-old dominant sprouts of all five species. On Missouri Ozark oak sites from site index 50 to 70, trees of this minimum height will be in the upper level of tree crowns at age 5.*

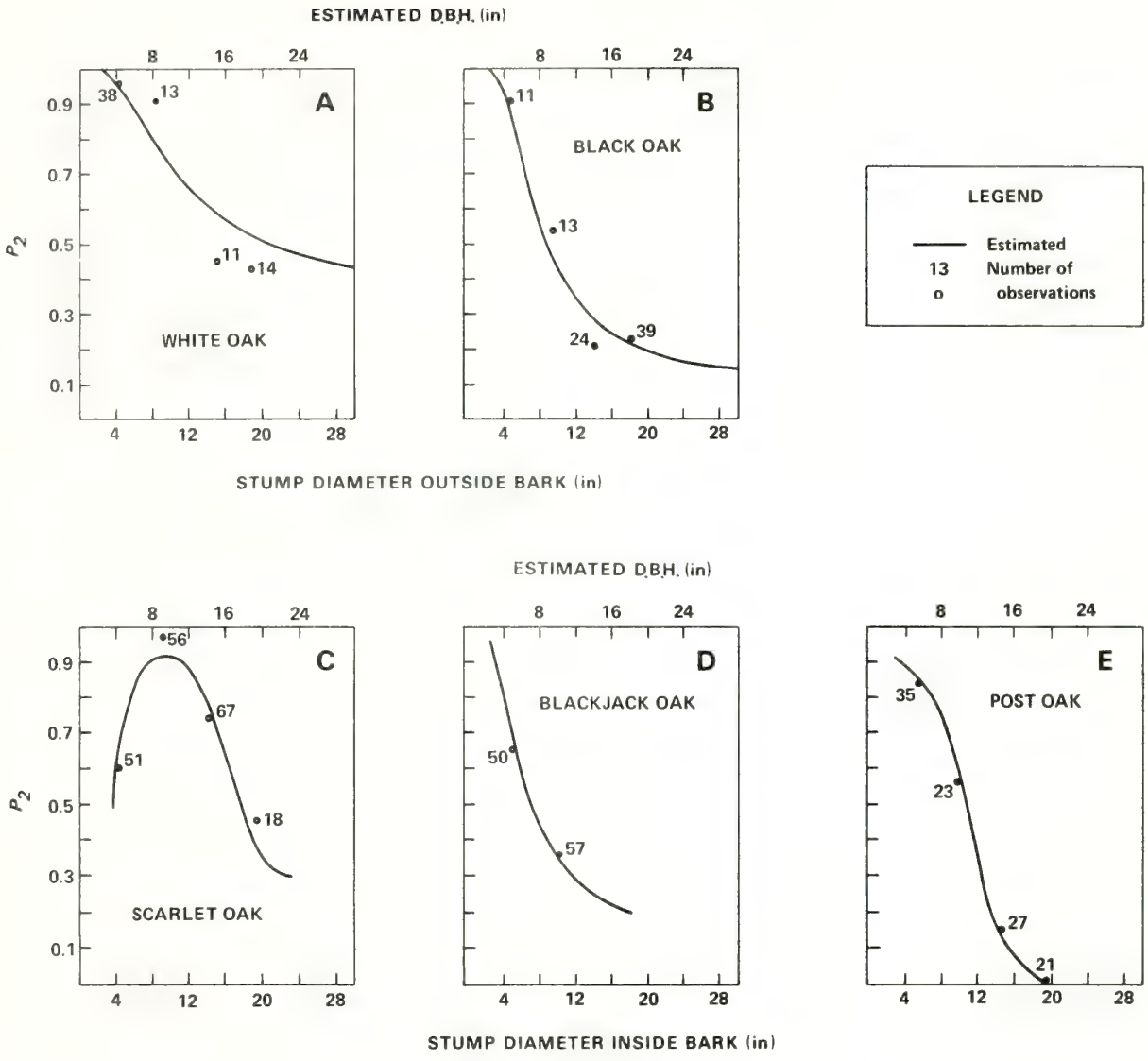

Figure 4. — *Estimated probabilities (P_2) by species in relation to tree diameter. (P_2 = probability that a stump with a living sprout at the end of the first growing season after cutting will have at least one codominant-or-larger sprout five growing seasons after cutting; regression equations and goodness-of-fit statistics are given in table 8. Observed values are means for diameter classes that included at least 10 observations per class.)*

Table 8. — *Regression coefficients for P_2 equations represented by figure 4*[1]

Species	B_0	Independent variables[2] X_1	X_2	X_3	X_4	Number of observations
Black oak	[3]-2.5758**		24.3594**			89
White oak	-0.8478**		18.3965**			76
Scarlet oak	-6.1144**	2.1195**		-0.1611**	0.0034**	192
Post oak	2.4148*			-0.0203**		106
Blackjack oak	-2.3309**		16.1399**			107

[1]Equations are of the form: $P_2 = \{1 + \exp[-(B_0 + B_1X_1 + \ldots B_nX_n)]\}^{-1}$, where P_2 is the probability that a stump with a living sprout at age 1 has a codominant or larger sprout at age 5.

[2]X_1 = Stump diameter (inches) = DIAM (outside bark for black and white oaks, inside bark for other species); X_2 = 1/DIAM; X_3 = $DIAM^2$; X_4 = $DIAM^3$

[3]Significance levels are based on "t" tests (H_o : B = 0) and are : * = 0.05, ** = 0.01; $p < 0.01$ for all regression F tests. Goodness-of-fit was also tested by chi-square for differences between observed and predicted numbers of stumps with codominant or larger sprouts among probability intervals of width 0.05; all chi-square values were nonsignificant at the 0.05 level. Goodness-of-fit was based on the above relations because the customary measure, the error mean square, is not appropriate when the dependent variable is dichotomous.

or conversely, diameter-dependent estimates have been averaged over unknown variation in tree age (e.g., estimates of P_1 for scarlet, post, and blackjack oaks). In contrast, the estimates of P_1 for black and white oaks differentiate effects of parent tree age and diameter (figs. 1 and 2).

Apparent effects of site quality on oak sprouting are minor in comparison to apparent age and tree diameter effects, based on the regression relations derived for black and white oaks. Site index also explained very little of the variation in height of dominant sprouts of black and white oaks after 5 years of growth. For this reason, definition of codominance was not adjusted for variation in site index in deriving equations for P_1.

Although no statistically significant trends were found for the proportion of oak stumps that sprout in relation to season of cutting, such trends might be expected because of seasonal changes in root carbohydrate reserves that support sprout growth (Kramer and Kozlowski 1960). Consistent with this expectation, Clark and Liming (1953) found that the proportion of blackjack oaks that sprouted in Missouri was lowest in June at about the time of full leaf development; sprouting thereafter gradually increased to a plateau in the dormant season before declining in early spring (April). Assuming that real seasonal differences in sprouting capacity do exist for oaks, estimates of P_1 (figs. 1, 2, and 3) should represent reasonable annual averages for each species because trees were sampled over both dormant and growing seasons.

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EARCH PAPER NC-150

Natural Regeneration

of northern hardwoods in the northern great lakes region

by Carl H. Tubbs

NORTH CENTRAL FOREST EXPERIMENT STATION
FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

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NATURAL REGENERATION OF NORTHERN HARDWOODS IN THE NORTHERN GREAT LAKES REGION

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The forest types collectively known as "northern hardwoods" (Quigley and Babcock 1969) occupy nearly 100 million acres in eastern North America. They extend roughly from Minnesota to the Atlantic coast and include parts of southern Canada. The area coincides approximately with Braun's (1950) hemlock-white pine-northern hardwood region and the Society of American Foresters (1954) northern region.

Prominent species are sugar maple, American beech, red maple, basswood, yellow birch, eastern hemlock, eastern white pine, the ashes, elms, and, in the northeast, red spruce. Northern white spruce, northern white-cedar, and black cherry are also common associates. American beech is confined to the eastern portion of the Great Lakes. As many as 17 cover types (Society of American Foresters 1954) may be considered "northern hardwoods". Ecologically, these types are related by successional trends that, under current climatic conditions, result in an abundance of sugar maple or beech.

The Great Lakes portion of the northern region has been repeatedly glaciated; geologically, the soils are young and the rolling topography contains a complex mixture of soils that are often influenced by ground water. The vegetation is also complex and many cover types are often found on a limited area.

The Great Lakes climate is characteristically humid (U.S. Department of Agriculture 1941) but the average precipitation varies from 25 inches in the west to 35 inches toward the east. Average mid-day July humidity ranges from 55 to 65 percent. Temperatures may drop as low as -50°F. during the winter and rise to 100°F. or more in the summer. Frost-free periods may be as short as 40 days in the northern interior but may extend over 170 days in southerly areas near the Great Lakes.

Establishing regeneration is an essential first step in forest management. Fortunately, most northern hardwood species can be regenerated without planting or artificial seeding. The purpose of this report is to review the information regarding the regeneration of northern hardwoods in the northern area of the Lake States. The first portion of the report focuses on the silvical characteristics of the major species, sugar maple and yellow birch, that affect regeneration, and the second describes the influence of silvicultural practices on regeneration.

The studies reported here were mostly done in the Upper Peninsula Experimental Forest in Michigan and the Argonne Experimental Forest in northeastern Wisconsin. These forests are in a region of heavy concentration of "northern hardwood" (fig. 1). Consequently, the results are applicable primarily to those northern forest areas and types whose successions will tend toward sugar maple, sugar maple-beech, sugar maple-basswood and to associations of hemlock-yellow birch and red maple.

Securing some sort of commercially important natural regeneration is usually a simple matter in most northern hardwood stands. On most sites the key to adequate regeneration is a supply of well established advanced seedlings and saplings. The tolerant maples are easily established after most partial cutting methods and respond well to subsequent release (Tubbs 1968). The chief problem is adequate representation of species either less tolerant or aggressive than the maples. Other concerns are stem quality and providing suitable browse for game animals or delaying tree regeneration where this is desirable for birds, animals, or esthetic reasons.

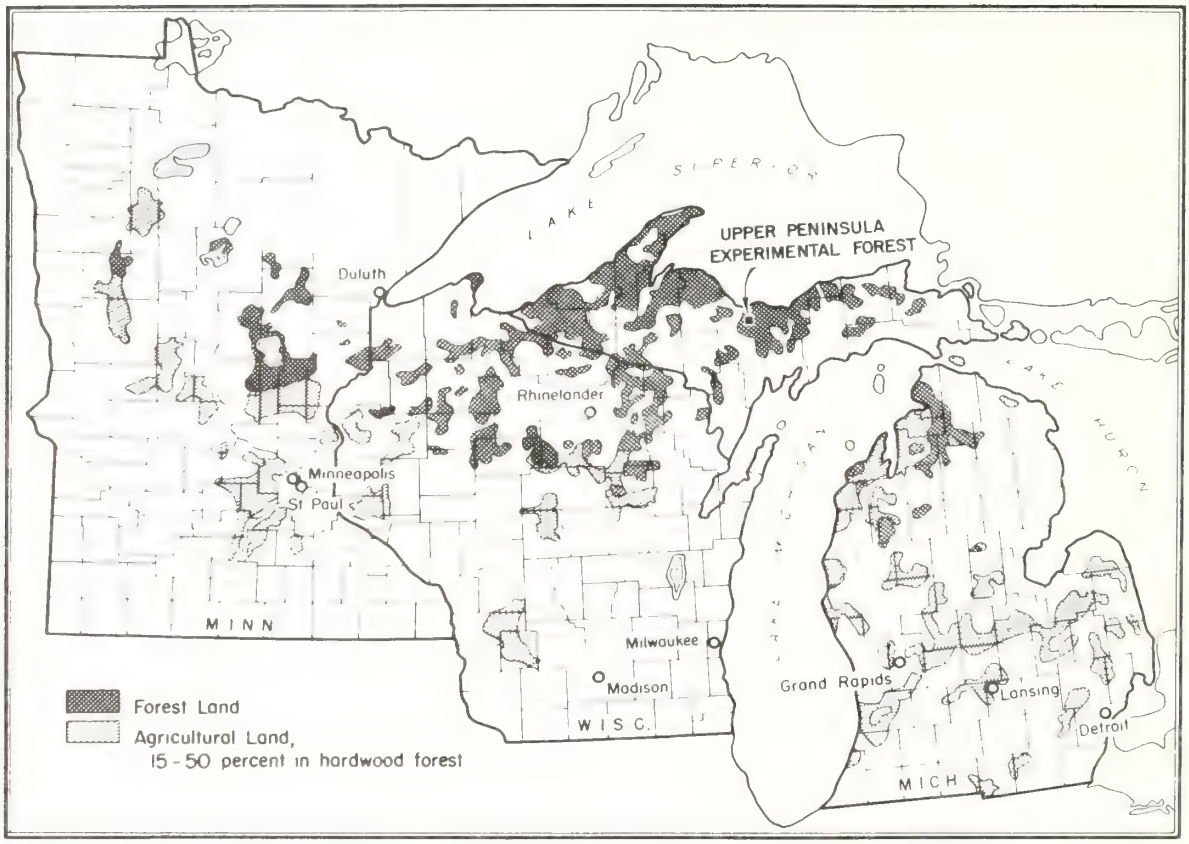

Figure 1. – *Concentrations of northern hardwoods in the Lake States.*

SILVICS

The Role of Sprouts

Except for basswood, sprout reproduction originating from stumps of old trees is usually undesirable for high quality timber production because of poor survival and form and propensity for extensive rot. Sprouts from seedlings and saplings are acceptable (Jacobs 1974). Clearcutting stimulates sprout growth (Eyre and Zillgitt 1953) as does heavy cutting in general (fig. 2). In old-growth stands, sprouting is greatest from stumps of young trees. Church (1960) observed that deer browsing reduced both sprout numbers and height growth. Fewer stumps sprout as overstories become denser. In second-growth[1], sprouting is not related to tree size or stand density but the percentage of stumps with sprout declines with increasing time since cutting.

In addition to poor form, stump sprouts are subject t rots that enter directly from the decaying parent stump or from the stubs of dead companion sprouts (Campbe 1938). Butt rot is more likely on sprouts that arise fror large stumps and those originating high on the stump Red maple is the species most susceptible to sprout but rot followed by paper birch, basswood, sugar maple black cherry, and white ash. Large stubs of dea companion sprouts with mature wood connection usually lead to butt rot of the surviving sprouts.

Consequently, sprout clumps should be thinned early generally before age 20; sprouts with large stum wounds should be discriminated against, sprouts fror small stumps should be favored, and old sprout clump should be either entirely cut or entirely left alone.

Sprout growth makes desirable game browse. Thinnin from below in young sugar maple pole stands ca produce abundant sprouting (Church 1960) and may b a useful technique for foresters interested in brows production.

[1] *Second-growth is defined here as stands with less than 50 square feet of saw log-sized (9.6 inches d.b.h. minimum) trees and frequently overstocked with poles and/or saplings.*

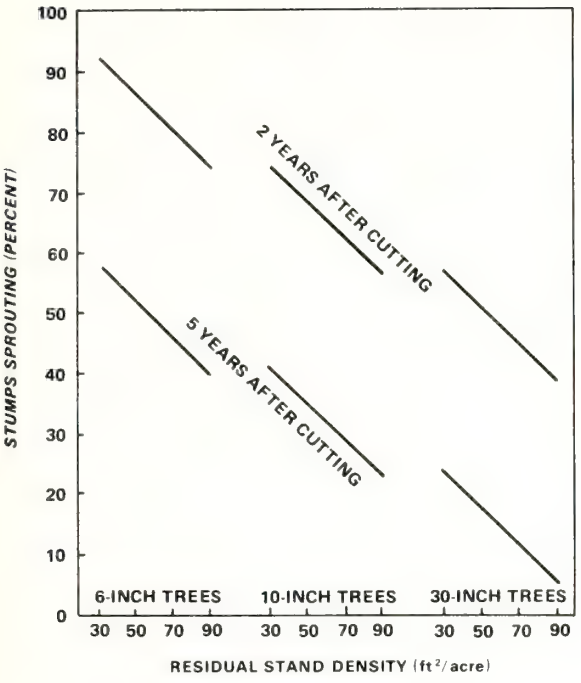

Figure 2. — *Effect of stand density, tree diameter (inches at breast height), and years since cutting on the percentage of old growth sugar maple stumps with living sprouts (Church 1960).*

The Role of Seedlings

Most hardwoods, balsam fir, and hemlock are prolific but irregular seeders. Poor crops or failures may occur often enough to significantly affect regeneration (Godman and Mattson 1976). When trees reach the large pole stage (8 to 10 inches d.b.h.) moderate crops are produced. Often several species bear good crops during the same year (table 1). In one study, 8 to 11 million seeds per acre fell in a year in a mature maple stand (Benzie 1959). As many as a million seedlings per acre may persist for the first year; few survive to the second year, but as many as 10,000 can survive to be more than 5 feet tall (Eyre and Zillgitt 1953).

The seeds of most commercially important species mature in the fall. White ash, black ash, sugar maple, beech, and red oak seeds are dispersed during leaf fall; eastern hemlock, yellow birch, and basswood seeds are dispersed throughout the winter months (U.S. Department of Agriculture 1974). Red maple and American elm seeds fall during late spring and early summer.

Table 1. — *Frequency of seed crops at the Argonne Experimental Forest (26-year average)*

(Years)

Species	Interval between good or better crops		Number of successive failures or good crops	
	Average	Range	Good or better	Poor or fail
HARDWOODS				
Black ash	3.6	1 to 8	2	7
Paper birch	2.7	1 to 8	2	5
Northern red oak	2.6	1 to 7	3	2
White ash	2.6	1 to 6	2	4
Yellow birch	2.7	1 to 8	2	3
Sugar maple	2.6	1 to 4	2	2
American elm	2.2	1 to 6	3	5
Red maple	2.1	1 to 6	4	5
Bigtooth aspen	1.5	1 to 3	6	2
Quaking aspen	1.4	1 to 3	6	2
CONIFERS				
Red pine	6.2	3 to 11	1	2
White pine	2.6	1 to 7	2	3
White spruce	2.5	1 to 5	2	3
Jack pine	2.4	1 to 6	7	2
Black spruce	1.9	1 to 4	5	1
Balsam fir	1.9	1 to 3	3	2
Hemlock	1.7	1 to 3	5	2
Northern white-cedar	1.6	1 to 3	6	2

Seed of most species is dispersed 300 to 400 feet by wind; in winter yellow birch seed may be blown long distances over the snow after thaws glaze the snow surface. Beech and oak seeds drop close to the tree.

Most species germinate readily after natural stratification. However, (except for maple) many newly germinated seedlings fail to penetrate the leaf mat and succumb because of low moisture and high temperature, which may exceed 150°F. on exposed leaf surfaces (Tubbs 1969a).

The timing of seed fall and length of time seed is exposed to dormancy-breaking conditions influence the number of seed germinating and surviving. In the Upper Peninsula, for example, sugar maple seed falls before and during leaf fall. The seed is buried between leaf layers where it is protected from temperature and moisture extremes. It germinates best at low temperatures (about 34°F.) and begins growth early in the spring when the leaf mat is wet and can be penetrated by young seedlings (Tubbs 1965). Yellow birch seed, on the other hand, drops after leaf fall and accumulates on top of the leaf mat. Optimum germination temperature for this species is higher than maple (about 50°F.) and germination normally begins later in the spring when the leaf mat surface begins to dry and becomes hard. By the time that temperature is favorable, the small birch seedlings are unable to penetrate the mat.

Birch germination depends on the length of time the seed is under dormancy-breaking conditions. Because yellow birch seed falls from September to June (Eyre and Zillgitt 1953), a year's seedfall receives various periods of dormancy-breaking conditions and optimum germination temperatures vary as a result. In one study, birch seeds sown outdoors after January germinated during the summer while those sown before January germinated in spring (Tubbs 1963). It is not uncommon to see the forest floor covered with newly germinated birch during wet periods anytime during the growing season. Seedlings resulting from late germination also cannot penetrate the leaf mat or are smothered by the October leaf fall. Consequently, scarification or burning to reduce leaf litter is necessary to produce the greatest number of birches and perhaps other small-seeded species as well.

Soil moisture is important in determining which species will dominate. Assuming other requirements are met, normally sugar maple will quickly become predominant after disturbances on well drained areas while on less well drained areas yellow birch and red maple will generally be better represented:

	Dominant stems	
	Well drained	Imperfectly drained
	— (Percent) —	
Hemlock	4	39
Sugar maple	58	10
Red maple	27	13
Yellow birch	3	10
Balsam fir	*	24
Other	8	4
	100	100

Poorly drained areas are usually invaded by mixtures of red maple, American elm, black ash, and various conifers. Ultimately, however, sugar maple tends to dominate all but the coarsest sands and swamplands (Braun 1950).

Many of the important northern hardwood tree species are shallowly rooted (red maple and white ash seedlings develop tap roots on deeper soils not influenced by ground water). The shallow-rooted tendency is accentuated on predominantly podsol soils, which characteristically have shallow A_1 horizons and pronounced A_2 horizons. In forest situations, most (90 percent or more) of the feeder roots of maple and birch are located in the top 3 or 4 inches of soil. Usually the leached A_2 horizon prevents any significant root development in underlying horizons. This restricts soil water supply to young seedlings. Forest disturbances or droughts that tend to dry out the upper soil layer may affect small seedling stands profoundly on soils that have shallow rooting zones because of a leached layer, high ground water, or bedrock.

The most abundant species in the northern hardwood types are at least moderately shade tolerant. Logan (1965, 1966a, 1966b, 1969, 1973) found that all species normally considered part of the northern hardwood group grew best in some shade except white pine, balsam fir, and white spruce; these species grow well in both partial shade and full sun (table 2).

"Tolerance" is a useful but potentially deceptive way for foresters to describe the general behavior of tree seedlings under various light conditions. Any one species' ability to grow under shade depends on site factors, such as moisture, temperature, and nutrients, as they are reflected by seedbed, soils, and amount and composition of overstory as well as the competitive

potential of other plants. The effect of these factors change as the seedlings develop. As seed or newly germinated seedlings, northern hardwoods are generally benefited by shade, which moderates temperatures and conserves moisture while allowing adequate light for growth. Partly because competing plants, such as grasses and shrubs, have much higher light saturation points than trees, partial shade also reduces the competitive potential of "intolerant" trees, grasses, or shrubs. However, once established, all northern hardwood species respond to increases in light by growing faster. At this point, some species, generally the shorter lived, require open conditions; the ashes and balsam fir for example, must have some release after establishment in order to survive, while others, such as the maples, hemlock, and yellow birch, may continue to grow slowly for long periods under heavy shade yet still retain the ability to grow rapidly after release from the competing overstory.

Table 2. – *Effect of shade on seedling height growth (from Logan)*

Species that grow well in deep shade[1] or half shade[2] but not in full sunlight:
Sugar maple
American beech
Species that grow well in one quarter shade[3] or half shade but not in full sunlight:
Sugar maple
American beech
Basswood
Yellow birch
White ash
Eastern hemlock
Species that grow best in half shade:
Paper birch
American elm
Silver maple
White-cedar
Species that grow well in half shade or full sunlight:
Eastern larch
Balsam fir
White pine
White spruce
Red pine
Species that grow best in full sunlight:
Jack pine
Black spruce

[1]13 percent full sunlight.
[2]45 percent full sunlight.
[3]25 percent full sunlight.

To further complicate matters, competition from other tree and lesser plant species influences a species' ability to survive under given "light" conditions in forest environments. Yellow birch competes poorly under even the most favorable forest conditions if sugar maple is present in large numbers, for example.

In addition, a species' "tolerance" may differ from one part of its range to another (Spurr and Barnes 1973) as a result of climatic and genetic differences.

Overstories can affect species composition in a number of ways. Shade cast by overstories affects micro-climate by reducing temperature and light and altering soil moisture. But, within broad limits, the density of the overstory has little influence on tree species composition of the seedling stand for a wide range of types in the northern hardwood group (Tubbs 1968, Tubbs and Metzger 1969). However, full sunlight as produced by disturbances such as clearcutting changes species composition to a mixture of shrubs, herbs, and trees when well established seedlings are not present (Metzger and Tubbs 1971) (fig. 3). Instead of favoring intolerant tree species, complete exposure commonly kills shallowly rooted, small, tree seedlings and allows intolerant grasses and shrubs to dominate, sometimes for several decades.

The composition of the overstory affects composition of the reproduction (fig. 4). Nine years after partial cutting old growth stands whose overstory was composed of hemlock, red maple, yellow birch, and sugar maple, seedling stands numbered from 12,000 to nearly 80,000 seedlings (6 inches tall to 0.5-inch d.b.h.) per acre. The composition of these seedling stands was more related to the original overstory composition than to the amount cut. Stands with overstories containing many sugar maple also had many sugar maple seedlings and few seedlings of other species. On the other hand, fewer sugar maple seedlings were found in stands whose overstories contained yellow birch and red maple. Numbers of yellow birch and red maple increased as the proportion of hemlock and red maple increased in the overstory. But numbers of yellow birch in the understory were not related to numbers of birch in the overstory.

Even though overstory density has little effect on tree composition, it does influence the rate of invasion by shrubs and grasses (fig. 5). Very dense overstories favor herbaceous plants, especially in younger stands. When overstories are composed mainly of poles and large saplings, the tree seedling stand is densely shaded, sparse, and severely repressed (Godman and Tubbs 1973).

Figure 3. — *A complete clearcut block with an average of 1,900 saplings per acre and a heavy cover of raspberries, grass, and scattered clumps of trees, 16 years after cutting. The bulk of the saplings were 1 in d.b.h. and occurred in a small area (Metzger and Tubbs 1971).*

Reproduction, density, germination, survival, and height growth are influenced by overstory density. Sugar maple and yellow birch germination and survival are favored by partial shade (Cunningham 1965, Ashby 1961, Metzger and Tubbs 1971) (figs. 6 and 7). Germination and survival of both species may be adequate on better drained soils under full sunlight, however (Tubbs 1969b and 1969c). Germination and survival of many of the other more tolerant species, although not studied intensively, would probably be similarly affected by overstory density. Height growth of young yellow birch seedlings on well drained scarified sites may be better under full sunlight than in partial shade (fig. 8).

As overstory density increases, seedling height growth rate generally declines. The 10-year average height growth of maple seedlings more than 4 feet in height was much greater under overstories originally cut to 50 square feet of basal area per acre (9.6 inches d.b.h.+) than 90 square feet. Both sugar maple and yellow birch are similarly affected (Burton *et al.* 1969) (fig. 9). Every opening in the overstory promotes good growth of a few seedlings, however, even when overstories are dense and average growth is low.

Suppression by the overstory for as long as 35 years does not prevent sugar maple from responding quickly to more growing space (Tubbs 1968). Observation indicates that other tolerant hardwood species and hemlock respond similarly but to a lesser degree.

Heavy cutting may make sites temporarily wetter (Godman 1959), which can retard tree seedling germination and growth on poorly drained sites. Shrub and grass

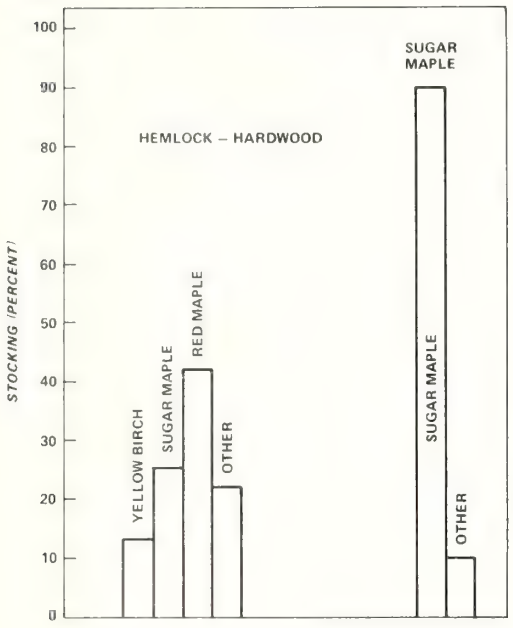

Figure 4. – *Species composition of the seedling stand 10 years after selection cutting in two forest types.*

invasions probably do not affect well established seedlings even after complete removal of overstories (Jacobs 1974) but may retard development of small seedlings and contribute to mortality after heavy overstory cutting (Metzger and Tubbs 1971). This is especially true of wet, shallow, or excessively well drained soils (Eyre and Zillgitt 1953).

Although there is an optimum combination of light, moisture and temperature for each species, a single species' performance in the forest depends on its ability to compete successfully with other trees and other plants. This may be only indirectly related to environmental factors. For example, in a controlled study of yellow birch regeneration requirements, only 6 of 64 different combinations of seedbed, light, and soil moisture did not support at least some birch seedlings after 2 years. In more than half the combinations, birch seedlings grew well (Tubbs 1969a). However, in field studies only a limited number of these combinations allowed birch to successfully compete with sugar maple (Tubbs and Metzger 1969) even though maple inherently grows slower than birch (Logan 1965) regardless of light conditions. Other studies (Tubbs 1973) showed that

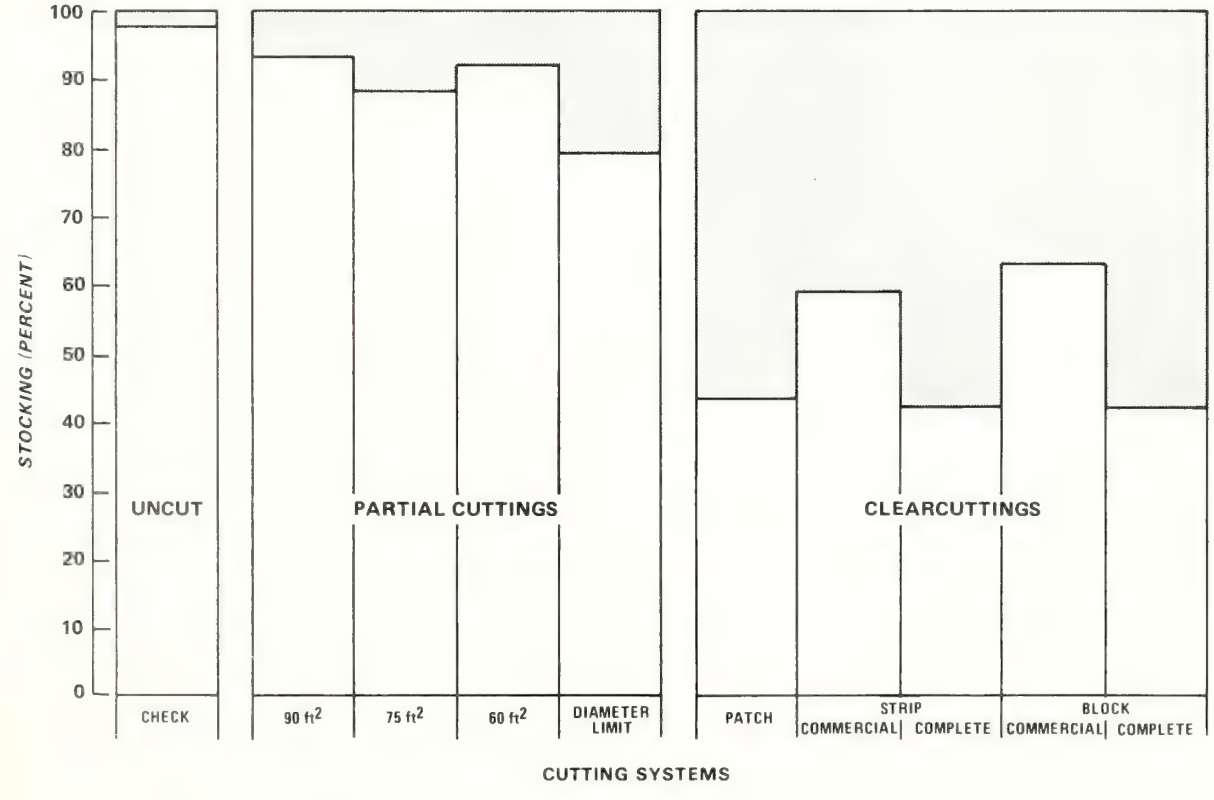

Figure 5. – *Average percentage of quadrats stocked with at least one tree of desirable species dominating 15 years after cutting. Gray area: Unstocked, or shrub or undesirable tree dominant.*

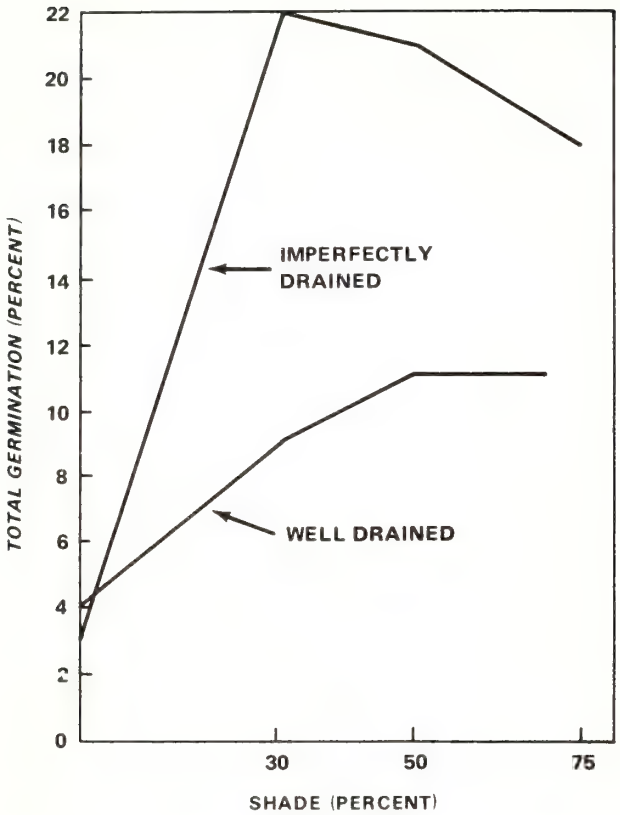

Figure 6. — *Germination of yellow birch by shade and drainage (Tubbs 1969).*

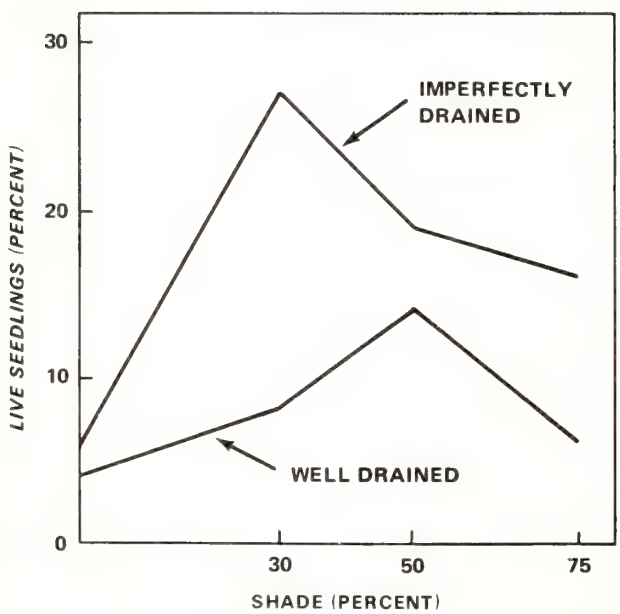

Figure 7. — *Live birch seedlings remaining after the second growing season by site and shade (Tubbs 1969).*

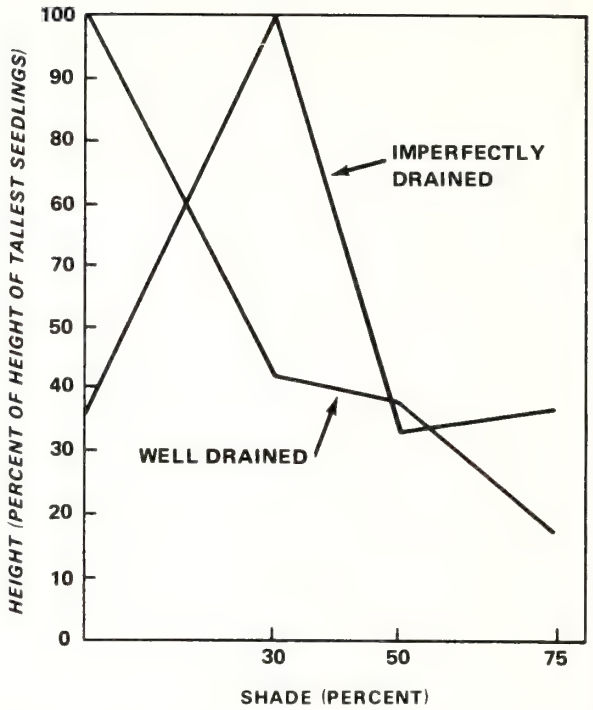

Figure 8. — *Percent of the height of tallest yellow birch seedlings on mineral soil seedbeds by moisture and shade (Tubbs 1969).*

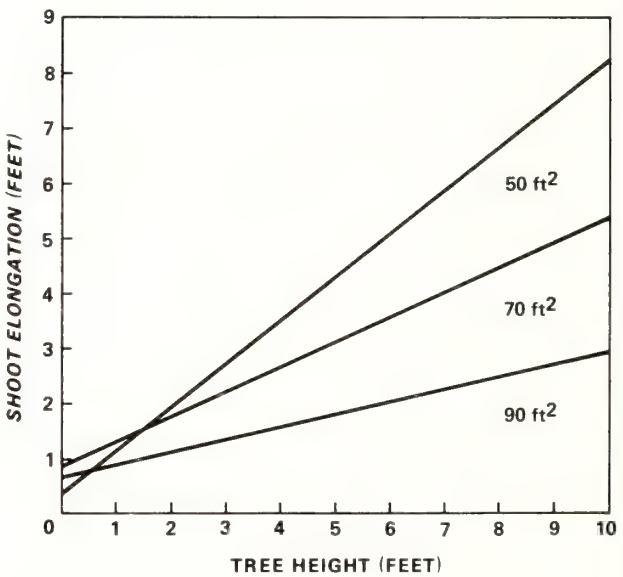

Figure 9. — *Maple shoot elongation in relation to tree height for three overstory densities (basal area) in the lowland hardwoods types (Metzger, unpublished M.S. thesis).*

maple exudes a growth inhibitor that prevents yellow birch establishment even though the environment is otherwise favorable. In forest situations, maple's ability to become established and survive under dense shade and grow rapidly when light conditions improve allows it to so dominate the reproduction stand that when more favorable conditions occur for other species they are unable to become established. In addition, rapid re-invasion of sugar maple into areas where it was removed causes a decline in birch numbers, apparently because of the inhibitor previously mentioned.

Field studies have shown that when sugar maple re-invades slowly and other environmental factors are suitable for birch growth, yellow birch stocking increases greatly (figs. 10 and 11).

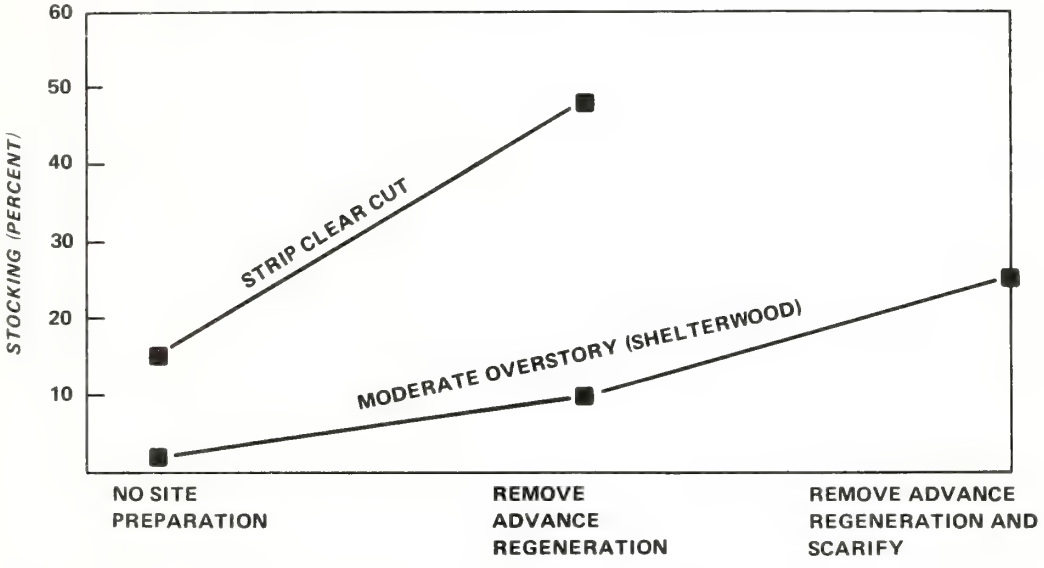

Figure 10. — *Influence of cutting method and site treatment on percent of sample quadrats dominated by yellow birch on moderate to well drained sites (Tubbs 1969).*

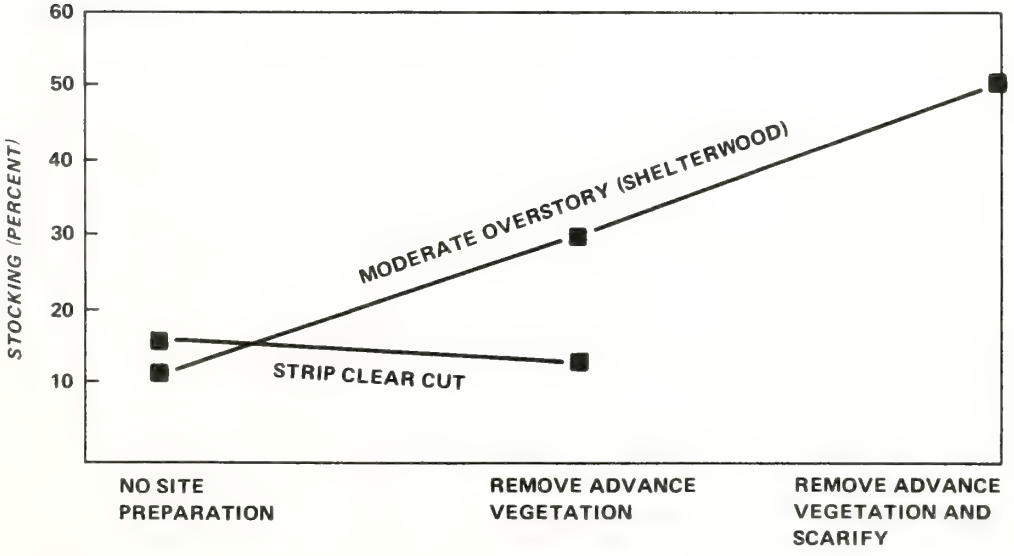

Figure 11. — *Influence of cutting method and site treatment on sample quadrats dominated by yellow birch on poorly drained sites (Tubbs 1969).*

Red maple sprouts commonly crowd out other tree species (Eyre and Zillgitt 1953). Beech competition is less often a problem in the Lake States than in the Northeast. Curtis and Rushmore (1958) suggest that heavy cutting may help favor maple over beech under certain circumstances. Arend and Scholz (1969) point out that red oak in northern hardwood stands competes poorly, as do other intolerant species. Basswood apparently competes favorably; it reproduces well from sprouts, which apparently are vigorous enough to compete with the ubiquitous sugar maple. Ironwood also competes well with sugar maple; in some cases it may even become a problem. It produces viable seed long before other northern hardwoods and may be prolific in openings made in young hardwoods.

Natural Form and Quality

Of the major species, red and sugar maple have the poorest natural form and quality. This is not noticeable during the seedling-sapling stage; even open-grown small maple saplings appear to have a strong central stem tendency, and defects such as forking quickly correct (fig. 12). However, maple crowns begin to break up between the small sapling and the small sawlog stages. Break-up is delayed in species such as white birch and basswood, which usually display good central stem tendencies. Even open-grown specimens of these latter species generally do not fork repeatedly as the maples do.

The quality of sugar maple seedlings is known to be partly genetically controlled. Kriebel and Gabriel (1969) found that seedlings of southern origin were more limby than those of northern origin. Excessive limbiness will ultimately result in short merchantable lengths, perhaps greater stem taper, and more limb-associated defects as trees mature.

Most northern hardwood species are alternately branched and do not have a true terminal bud; the maples, on the other hand, have opposite branching and a true terminal. It appears that damage to the apical portion of the stem has a longer lasting effect on the maples because the resultant forks are of approximately equal size (fig. 13); alternately branched species similarly damaged commonly have a clearly dominant fork member that would quickly return the tree to a single stem form.

The effect of these characteristics can be modified by the density and uniformity of the seedling sapling stand.

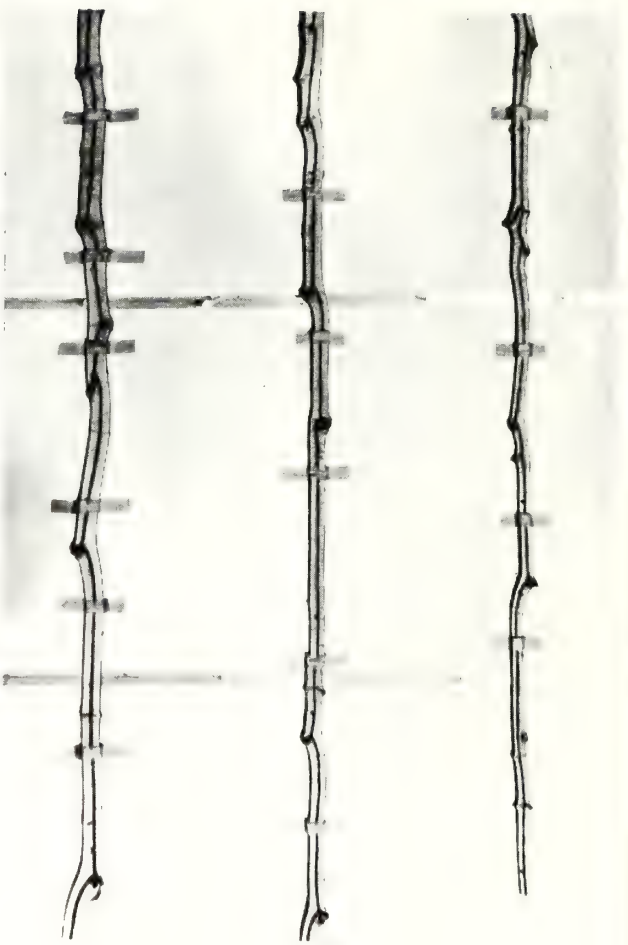

Figure 12. – *Longitudinal sections of the lower bole of sugar maple saplings show how radial growth corrects forking and associated crook and sweep (Jacobs 1969).*

Dense, uniform stands accelerate self pruning and tend to delay crown break-up. Widely spaced seedlings develop into poorly formed, defective trees with excessively large crowns and short merchantable lengths caused by early crown break-up (fig. 14). It appears that maple saplings growing in the shade of larger trees develop better form than dominant trees (Tubbs 1969b).

However, severe suppression of sapling sized maple results in profuse epicormic sprouting; when suppressed trees are released, many of these sprouts develop into large limbs that reduce quality at best and merchantability at worst. Other species appear less prone to epicormic sprouting (Eyre and Zillgitt 1953) but because they are less shade tolerant than the maples, severe suppression kills them.

Figure 13. – *Broken fork of pole-size sugar maple. Forks are caused by damage to the terminal bud by insects or physical factors such as wind or ice. Subsequent high winds or ice storms may break forks.*

Although dense side shade appears to be desirable in developing good stem form and clear boles, crown size and vigor are reduced in contrast to more open growth trees (Erdmann *et al.* 1975). Small crowns lead to increased epicormic sprouting both before and after release (Godman and Mattson 1970). Although it is often thought that increased light on epicormic buds produces sprouting, light plays at best a subordinate role to crown size and position in this regard (Books and Tubbs 1970).

Whether it is possible to develop, through cultural operations, crowns adequate to reduce epicormic sprouting under conditions unfavorable for forking and yet not reduce merchantable bole length is still a matter for research.

Sugar maple seedlings are often flattened by deep snow; subsequent growth does not entirely correct the stem curvature that results and maple saplings characteristically have what foresters call a "club foot" shape: the root collar area is noticeably swollen and from this the stem extends horizontally for a short distance to sharply curve to a vertical position (Fayle 1965). This phenomenon seems to have no effect on future merchantability.

Figure 14. – *The wide spacing of this plantation has caused low forks to persist, reducing merchantable length. Although the trees average 9 in d.b.h., the clear length is only 8 to 9 ft.*

Affect of Damage on Form and Survival

Browsing, especially by white-tailed deer, has been considered harmful to both form and numbers of seedlings. However, Jacobs (1969) showed that winter-browsed sugar maple seedlings grow about as well as unbrowsed seedlings and that ultimate tree form is not affected by severe browsing. Although forks are formed after the terminal bud is removed, one of the fork members quickly becomes dominant and the resultant crook is corrected by radial growth.

Damage by bud miners is prevalent in seedling sugar maple stands (Kulman 1967, Tigner 1966). Insects damage terminal buds causing the seedlings to fork. In the seedling-sapling stage, damage to form is not lasting but it can be serious to older trees.

Various birds feed on the winter buds of hardwoods; squirrels, mice, porcupine, and hare can kill or deform trees by winter feeding on bark.

Frost damage to northern hardwood seedlings has minor impact although such damage is common. Damaged seedlings usually grow as well as those undamaged (Tubbs 1969, Godman and Krefting 1960). Early fall frosts followed by late spring frosts can kill young yellow birch seedlings, especially those in full sunlight. Partial shade moderates low temperatures reducing damage, but heavy shade produces small seedlings that cannot survive even slight damage (Tubbs 1969).

Godman and Krefting (1960) observed that frost damage of yellow birch resembles that caused by deer browsing. Wind or snow break off frost-killed portions of twigs and stems, leaving a ragged tear like that of deer damage. Similarly, stem damage caused by Diaporthe resembles frost damage or can be mistaken for deer or frost damage after affected stem parts break off.

The ability to survive damage appears to be related to the "vigor" of the seedling. The amount of stem destroyed is less important than the vigor of the tree and the size and position on the buds left uppermost (Metzger 1977). Tree vigor is partly a reflection of growing condition: if seedlings are in good growing environment a high degree of damage can be tolerated. For example, in one study, most large yellow birch seedlings that grew slowly on water-logged soils died after severe damage but most fast-growing trees on well drained soils overcame the damage (Kamensky and Erdmann 1973). It is also known that repeated defoliation by insects can extend the normal hardening off process of trees, increasing their vulnerability to late summer frosts, especially when soil is dry (University of Wisconsin 1964). Presumably, defoliation by other agents could produce the same effect.

Breakage of seedlings and saplings during winter logging usually does not hinder regeneration. During removal of a shelterwood overstory of 80 square feet (4.6 inches d.b.h. and larger) from a sugar maple stand, nearly half the seedlings were damaged and a third destroyed (Jacobs 1974). However, mortality appeared to be confined mainly to seedlings less than 0.6 foot in height and stocking had only declined to 96 percent (45,000 seedlings per acre). Seedling sprouts that resulted from stem breakage grew rapidly and are considered desirable.

Winter cuts of a shelterwood over a yellow birch reproduction stand caused insignificant damage (Tubbs and Metzger 1969). However, summer logging in shelterwood stands may cause serious damage (Godman and Tubbs 1973). Apparently shallow-rooted seedlings are sensitive to summer logging.

Repeated partial cutting normally does not greatly reduce stocking of reproduction in selection stands (Tubbs 1968). Exceptions may occur in areas prone to sod and brush invasion. Where residual overstories are lightly stocked and advanced reproduction is not well established or absent, tree seedlings may not be able to become established in sodded areas for many years.

Serious wild fires are rare in the northern hardwood types. Spring ground fires can kill most reproduction-size trees (Burton *et al.* 1969), but reproduction damaged in fall ground fires resprouts the following spring. Repeated ground fires kill large saplings and poles, and hot slash fires kill sawlog-size trees. Wind and glaze are not especially damaging to small poles and saplings in managed all-age stands, but glaze may permanently bend small trees in even-aged stands or older forked trees. Sunscald appears to be most significant on young, sapling-size yellow birch and sugar maple, especially in even-age stands (Godman 1957). This type of damage seems to be sporadic, requiring conditions that do not occur often.

It is generally accepted that the density of seedling stands ultimately influences tree form. Studies are underway to determine quantitatively the relation between quality and density. In general, when exposed to light, branches of most tolerant northern hardwood species maintain themselves for long periods (Erdmann *et al.* 1975). The long term effects of sparse stocking are short boles and low forking (Godman 1969), (fig. 14). Probably at least 5,000 well spaced saplings per acre are needed to produce adequate quality (Jacobs 1974).

SILVICULTURE

Single Tree Selection

Single-tree selection for the northern hardwood type is defined in detail by Arbogast (1957). In general, the choice of trees begins with the largest and poorest and proceeds through the structure to the smallest. The cut is limited by the basal area chosen for each size class in the residual stand. Numerous studies (Tubbs 1969b) have illustrated the ease with which sugar maple regeneration is obtained with this practice (fig. 15). Within 5 to 10 years of the initial cutting, stocking with desirable species usually exceeds 70 percent and is commonly 90 percent or more regardless of overstory density (fig. 16). Overstory density affects growth of seedlings: cutting to leave only 30 feet of sawtimber (trees 10 inches d.b.h. and larger) produced dense sapling stands after 10 years while cutting to leave 90 square feet of sawtimber produced patches of saplings and many small seedlings.

However, dense second-growth pole stands seldom have many advanced seedlings because of the dense shade and/or scarcity of seed-bearing trees. In these

Figure 15. — *Sugar maple stand developing all-age structure after three cutting cycles, Upper Peninsula Experimental Forest.*

stands, improvement cutting or thinning normally does not immediately stimulate regeneration. Brush species cover even small openings quickly, but subside to be overcome by tolerant tree species in 10 years or so. In very young stands, sprouts may be dominant after cutting, along with various brush species (Church 1960, Ostrom 1938).

Group Selection

This technique has been used throughout the northern hardwood area in attempts to increase the production of moderately tolerant species. In the Upper Great Lakes this method is used primarily to promote yellow birch; consequently group size commonly ranges from 1/10 to 1/5 acre. One-tenth acre groups were shown to increase the proportion of yellow birch in old-growth stands in the Upper Peninsula. However, after 23 years many birch were overtopped by maple. Birch should have been released in the large seedling and sapling stage (Eyre and Zillgitt 1953). Yellow birch requires cool moist conditions to establish itself so the shady conditions of small group cutting tend to increase birch numbers especially if the area is scarified. Several moderately tolerant species have been promoted by some form of this technique in New Hampshire (Filip 1973) and Ontario (Burton *et al.* 1969). On the other hand, group selection in second-growth stands led to long-lived grass-brush invasions in Wisconsin (Metzger and Tubbs 1971).

The management of groups is unwieldy for large forest areas partly because of the groups' small size (1/10 to 1/5 acre) and because a large number of groups must be accounted for to schedule cleanings, thinnings, and reproduction cuts. When early cultural practices are not

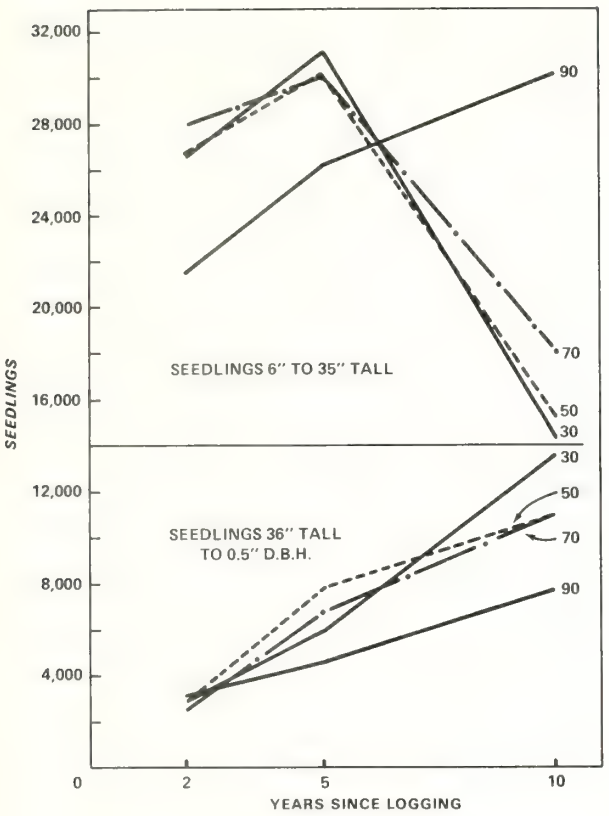

Figure 16. — *Abundance of sugar maple seedlings under different levels of residual overstory (30, 50, 70, and 90 ft² of basal area) (Tubbs 1969b).*

necessary, or on small tracts, group selection may be practical under present economic conditions (Roach and Gingrich 1968). It is an accepted practice in conjunction with individual tree selection: groups are not planned but are created when markers find a group of mature trees. If no attempts at scarification are made the resulting regeneration after cut is primarily of tolerant species; if scarification is done other species may invade.

Group selection has evolved to narrow-strip clearcutting (Marquis 1966) in the Northeast where it seems to accomplish about the same purpose in a more manageable way. However, uniformly successful application of strip clearcutting to promote either moderately tolerant or intolerant species has not been demonstrated in the northern Lake States. Here, cutting to promote less tolerant species has evolved from group selection to shelterwood.

Shelterwood

Shelterwood cutting is defined in detail by Godman and Tubbs (1973). In general, it requires a preliminary cut 10 years or so before final removal to establish advance reproduction from seed or seedlings. It is necessary to start this preliminary cut from below, removing the smallest trees first, then advancing to larger trees. The objective is to leave an overstory canopy which covers roughly one-half or more of the area (fig. 17). The final removal releases the advance regeneration.

Shelterwood cutting can produce fully stocked even-age stands of both tolerant and moderately tolerant tree species (Tubbs and Metzger 1969, Godman and Tubbs 1973). Shelterwood has been used to regenerate species that require shade or respond poorly to full sunlight during the germination-establishment period. Many northern hardwood species fall into this category. For example, both sugar maple and yellow birch may reproduce easily after strip clearcuts on well drained soils but even advanced growth may perish after complete overstory removal on other soils (Tubbs 1969b).

Two-cut shelterwoods experimentally done in Upper Michigan and northern Wisconsin (Godman and Tubbs 1973) illustrate several principles that must be followed to successfully regenerate dense, even-age stands.

The first cut must be from below. The dense shade cast by saplings and poles represses regeneration unevenly. Where groups of small trees are numerous, a patchy stand of various size seedlings and saplings may result (table 3). If not removed before overstory removal, the taller reproduction becomes excessively branchy.

Because basal area does not adequately describe crown size of forest-grown hardwood trees, regulation of overstory is best done by judging the amount of crown area to be left (Godman and Tubbs 1973). Where advanced regeneration is small and sparse, the crown area to be left should be relatively great to prevent invasion by brush and grass species. Where advanced regeneration is well distributed and large, up to 50 percent of the crown area may be left.

The timing of removal cuts is based on the vigor and density of the reproduction. Generally it should be safe to remove the overstory when the reproduction is 2 to 4 feet tall. Seedlings smaller than this may die on many sites after overstory removal. Overstories have been removed when reproduction is up to 10 feet tall without significant damage (Jacobs 1974).

Figure 17. – *Shelterwood stand 3 years after the initial cut.*

Table 3. – *Influence of different amounts of crown cover on stocking and height growth 7 years after a shelterwood cutting*

Stand number	Crown cover		Seedlings per acre	
	Initial cut	After 7 years	Total	More than 3.6 feet tall
	Percent		*Number*	
1	60	76	44,040	9,800
2	76	94	33,400	2,500
3	130	158	17,100	700

When it is desirable to increase the proportion of less tolerant or aggressive species, use of the shelterwood system with site preparation has been most successful on sites not conducive to rapid invasion of competing tolerant hardwoods (Tubbs and Metzger 1969). These sites generally have moderately and less well drained soils supporting red maple, American elm, hemlock and other conifers. Advance reproduction should be destroyed and the area scarified to provide optimum conditions. If scarification is not possible, poisoning of advanced regeneration will also increase the proportion of less tolerant species although not to the extent that scarification will (fig. 10). Eastern hemlock regeneration success is stimulated by artificial seeding after scarification.

Sprout growth may cause difficulties in prospective shelterwood stands that were previously partially cut and have developed some structure. For example, a recent preparatory cutting at the Upper Peninsula Experimental Forest has resulted in vigorous and widespread sprouting, which stemmed from stumps of the numerous poles and large saplings produced by partial cutting in the past.

Clearcutting

Clearcutting as used here refers to a regeneration cut that removes all trees from an area with the intent of starting a new even-age stand of natural regeneration by seed. It is important to distinguish and emphasize the difference between this and the final removal cut of a shelterwood system, which is intended to release advanced regeneration. The latter is also a clearcut. In the first case, clearcutting is a regeneration cut but in the case of shelterwood, clearcutting is simply a cutting used after a rotation for final release of reproduction. These clearcuttings are done for different reasons and are preceded by a different set of circumstances. Because confusion exists about the meaning of the term clearcutting, it appears to be wise to use the words final removal where the purpose of the clearcut is to release advanced regeneration and to use clearcut with the applicable modifier (i.e., commercial, with artificial regeneration, etc.) where clearcutting is done for some other purpose.

Accidental shelterwoods were often created in the past by clearcutting mature hardwood stands in which mortality or commercial selection for species or grades had previously opened up the overstory. When this happened advanced regeneration became well established and "clearcutting" produced a well stocked, even-age stand. In essence, the clearcutting was a final removal. Similarly, even-age stands of the future are not likely to require preparatory or seedling cuts near the end of the rotation because any regularly thinned northern hardwood stand will regenerate after mid-age. The final clearcut in this instance is also a final removal because its silvicultural purpose is to release advance regeneration.

Clearcutting trials date from 1926 in the Lake States. It appears that successful "clearcuts" were often due to the presence of well established advanced reproduction before cutting (Tubbs 1969b). A recently completed comparison of strip, block, and patch clearcuts of stands without large advance regeneration shows that stocking was variable, shrub and grass invasion common, and few intolerant or moderately tolerant species were produced regardless of the shape or orientation of the cutting area (Metzger and Tubbs 1971).

Because establishment of tolerant species is especially benefited by shade, strip clearcutting might be thought to be better than block clearcutting. However, in this study there were no differences in stocking between strips and blocks. A strip clearcutting in old-growth hemlock-hardwoods on a shallow silt loam at the Argonne Experimental Forest is still poorly stocked after 10 years. Another strip clearcutting study (1- and 2-chain-wide strips positioned N-S and E-W) at the Upper Peninsula Experimental Forest indicates that where all vegetation was removed, regeneration after a good seed year was plentiful on the better drained portion of the study. Yellow birch was prominent in the new stand. However, in the poorer drained portion of the study area, after a less bountiful seed year, reproduction was poor 5 years after cut and is composed primarily of sugar maple after 10 years. Where advance regeneration was not poisoned, the seedling stand after the removal cut was uniformly dense and composed primarily of sugar maple.

In essence then, soil type, soil moisture, and seed year are major influences on species composition after clearcuts. Following clearcutting, natural tree regeneration is likely to be irregular in size and distribution, most tree species will be tolerant, and areas may be invaded by undesirable species or dominated by sprout growth in some cases.

Apparently, complete overstory removal without well established regeneration may delay regeneration, especially on extremely wet or dry soils. On such soils overstory moderates temperature-moisture extremes, which is normally necessary for regeneration of northern hardwood tree species.

SUMMARY

Fully stocked stands of species such as the maples or beech are easily obtained by partial cutting. Repeated partial cutting under an individual tree selection system results in regeneration stands of many size classes while partial cutting done as part of a shelterwood system results in even-age regeneration stands.

Regeneration after partial cutting on wet soils will commonly be composed of a greater range of species than on the better drained soils, especially if sugar maple is not the dominant overstory species. On the better drained soils regeneration is predominantly sugar maple.

The occurrence of a northern hardwood species depends initially on seed production during favorable years. Seed production is usually adequate although sporadic enough to cause regeneration failures on clearcuts. Site factors, especially soil moisture, play an important role in determining the proportions of species that will germinate and survive. Competition between grasses, shrubs, and tree species affects both the density and composition of tree regeneration.

Partial shade generally benefits all northern hardwoods during establishment. In many situations northern hardwoods require partial shade for successful establishment but in a few can reproduce from seed without the benefit of shade. Partial shade also reduces the intensity of sprouting.

Once established, all are benefited by an open overstory. In forestry practice, the amount of opening is constrained by quality considerations: in all-age stands an overstory sufficient to encourage natural pruning must be maintained for the few hundred saplings normally present. In even-age stands, several thousands of reproduction-size stems are necessary to ensure natural pruning.

Light-seeded species are benefited by seedbeds that do not retard germination by quickly drying out or presenting physical resistance. The less tolerant or less aggressive species such as yellow birch and eastern hemlock can be regenerated by scarification and/or removing advanced regeneration in partial shade.

Clearcutting success has been variable. The most successful clearcuts have been on soils of moderate texture and drainage following good seed years. Clearcutting does not always produce desirable stocking of intolerant or moderately tolerant species. Consequently, the natural regeneration of moderately tolerant or tolerant species should be stimulated by partial cutting in selection or shelterwood systems.

These results may seem at variance with those obtained in other areas of the northern hardwood region. Both in southeast Canada and the northeast United States some form of clearcutting successfully produces desirable moderately tolerant and intolerant species (Burton *et al.* 1969, Trimble 1973, Filip 1973). However, both the climate and composition of the eastern northern hardwoods vary markedly from the northern Lake States. For example, American beech and red spruce are notably lacking in northern portions of Lake States forests and are prominent farther east. In the east, rainfall may be more than double that of average Lake States conditions and evapo-transpiration rates are generally less than in the Lake States. Consequently, it does not seem surprising that clearcutting by patch or strip should be more successful in those areas than in the northern Lake States where a partial overstory must protect young seedlings from excessive temperature and moisture loss in most instances. In those portions of the northern hardwood range where such species as black cherry, yellow poplar, and the oaks are mixed with northern hardwood species, patch clearcutting is an accepted practice.

RESEARCH NEEDS

Regeneration requirements of only a few species are well known. The birches have been intensively studied but other important species such as red maple, basswood, and the ashes have been largely ignored. The advent of strong multiple-use demands makes it necessary to understand the requirements of many tree species (such as eastern hemlock and red maple) that are important for both timber and recreational use. More significance is now attached to vegetation other than trees and to associated animal life not only because of their recreational value but because of their role in protecting the site. The behavior of species in natural communities has also only been occasionally studied by systematic methods so that the reasons for significant changes are difficult to judge. The discovery that tree species in the northern hardwood type may exude ecologically significant toxins or inhibitors deserves more study because these substances may play an important role in determining species occurrence and regeneration success.

In general, regeneration study has been limited to specific geographical areas so that important regional differences are difficult to discern and understand. It seems important to be able to distinguish these differences so that forestry practice will not be misapplied to similar appearing but ecologically different cover types.

The use of heavy machinery provides more economical and less wasteful methods of harvesting, so new regeneration methods are likely to be needed as new harvesting equipment becomes available. As more is learned of the genetics of hardwood species the necessity of finding ways to introduce better strains into natural forest areas will also be needed. Better genetic information may also aid in refining present practice in natural stands.

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1977. Natural regeneration of northern hardwoods in the northern Great Lakes Region. USDA For. Serv. Res. Pap. NC-150, 20 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

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OXFORD: 231:(77). KEY WORDS: northern hardwood, *Acer saccharum*, *Betula alleghaniensis*, natural regeneration, silviculture.

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MALL MAMMAL POPULATIONS fter a WILDFIRE in ORTHEAST MINNESOTA

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SMALL MAMMAL POPULATIONS AFTER A WILDFIRE IN NORTHEAST MINNESOTA

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Many studies have been done on small mammal populations following both wildfires and prescribed burns but only one, that of Krefting and Ahlgren (1974), pertains to wildfire in a forest community typical of northern Minnesota. The Roy Lake Fire provided an excellent opportunity to study the impact of extensive and severe wildfires on small mammal populations. This 1,368 ha fire occurred within the Boundary Waters Canoe Area of the Superior National Forest in the northwest tip of Cook County in northeast Minnesota in late August 1976. The study was limited to the most severely burned portions.

METHODS

Small mammal populations were assessed in three community types: aspen-fir-spruce, jack pine, and black spruce-jack pine. For each community (except the black spruce-jack pine), two areas were chosen for data collection—one severely burned during the Roy Lake Fire and the other a comparable control area outside the fire perimeter. A control area was not available for the black spruce-jack pine community, but because of similarities in understory composition, the jack pine control area was used for both the jack pine and black spruce-jack pine burn areas. Two small mammal assessment lines, spaced 120 m apart, were centrally located within each area. Each assessment line consisted of 25 stations spaced 15 m apart, with 2 snap traps located at each station. Where it was not possible to maintain a straight line and still remain within severely burned portions, the lines were 'dog-legged' in the cardinal direction away from the other assessment line.

The snap traps, 100 on each of the 5 areas, were baited with peanut butter on August 31, 1976. Traps were checked September 1 and 2, 1976, in the black spruce-jack pine burn area (total trapping effort equalled 100 trap station nights) and September 1, 2, and 3, 1976, in the other four areas (total trapping effort in each equalled 150 trap station nights). The traps were removed on the last day. The following information was recorded for each capture: species; capture location; weight; total length and length of the tail, hindfoot, and ear; sex, testes position, and size of nipples. Individuals were subsequently assigned to one of three age classes on the basis of body weight as defined by Buech (1974) (table 1).

Unless otherwise indicated, capture indices (C.I.) are based on the number of captures/1,000 trap station nights. A trap station night consisted of two traps set at a station for 24 hours.

Table 1.—*The weight-class limits used to define age class for three species*

(In grams)

Species	Juvenile	Subadult	Adult
Southern red-backed vole (*Clethrionomys gapperi*)	<14	14 to 19	>19
Deer mouse (*Peromyscus maniculatus*)	<16	16 to 21	>21
Masked shrew (*Sorex cinereus*)	< 2.5	2.5 to 3.9	> 3.9

RESULTS
Species Captured

On all areas combined, a total of 313 individuals were captured during 700 trap station nights (table 2). The five species that were caught, in decreasing order were: the southern red-backed vole (*Clethrionomys gapperi*), deer mouse (*Peromyscus maniculatus gracilis*), masked shrew (*Sorex cinerius*), rock vole (*Mecrotus chrotorrhinus*), and least chipmunk (*Eutamias minimus*). Red-backed voles were captured on all areas, deer mice and masked shrews on both burn and control areas in the aspen-fir-spruce and jack pine communities, rock voles on the aspen-fir-spruce control, and least chipmunks on the aspen-fir-spruce and jack pine control areas. None of the captured individuals showed any sign of fire-related injury.

Capture Indices

The highest capture index (C.I.) for each specie was 900 for the red-backed vole, 240 for the dee mouse, 47 for the masked shrew, 27 for the roc vole, and 7 for the least chipmunk. The highes index for all species combined was 1,207 in th aspen-fir-spruce control area, followed by 580 i the jack pine control. The dominant species i both the aspen-fir-spruce and jack pine contr areas was the red-backed vole. The deer mous was also abundant in the aspen-fir-spruce contr but was not abundant in the jack pine contro Other species in the aspen-fir-spruce and jac pine control areas were comparatively low. I general, the aspen-fir-spruce community suppor ed the highest number and diversity of sma mammals, followed by the jack pine and blac spruce-jack pine communities.

In the aspen-fir-spruce and jack pine commun ties combined, the number of individuals of a species captured in burned areas averaged 16 pe cent of that in control areas—13 percent for th red-backed vole, 25 percent for the deer mous and 33 percent for the masked shrew. E community type, this percentage was highest f red-backed voles and masked shrews in aspen-fi spruce community, and for deer mice in the jac pine community. In fact, in the jack pine comm nity, the number of deer mice captured in th burned area exceeded that captured in the contro

Table 2.—*Small mammal populations in burned and control communities of three different types on the Roy Lake Fire expressed by capture index (C.I. = captures/1,000 trap station nights)*

Species	Total captures	Community type: Aspen-fir-spruce			Jack pine			Black spruce-jack pine		Aspen-fir-spr plus jack pi
		Burn	Control	Burn control	Burn	Control	Burn control	Burn	Burn[1] Jack pine control	Burn control
		C.I.	C.I.	*Percent*	C.I.	C.I.	*Percent*	C.I.	*Percent*	*Percent*
Red-backed vole	241	147	900	16	40	500	8	20	4	13
Deer mouse	50	20	240	8	47	27	175	-	-	25
Masked shrew	16	13	33	40	13	47	29	-	-	33
Rock vole	4	-	27	0	-	-	-	-	-	0
Least chipmunk	2	-	7	0	-	7	0	-	-	0
TOTAL	313	180	1207	15	100	580	17	20	4	16

[1]A control was not obtained, but due to similarities in the understory, values from the jack pine control r used for comparison.

Age Class Distribution

Age class distribution, mean body weight, sex ratio, and reproductive data all provide useful information for interpreting the source of populations on burned areas, i.e., were individuals prefire residents, postfire immigrants, or a combination of both? For all community types combined, the age class distribution of the red-backed vole and masked shrew was similar between burned and control areas (table 3). For red-backed voles, subadults and adults codominated the age class distribution and juveniles were few. For masked shrews, all but one capture were subadults. However, for deer mice, no adults were captured, and although juveniles and subadults were equal on both control areas combined, juveniles predominated on the burned areas.

Mean Body Weight

For red-backed voles and deer mice the mean body weight of individuals captured on the burn and control areas was similar (table 4). Although mean weight for all types combined was slightly less on burned areas for both species, it was not significant.

Sex Ratio

Where sample size was adequate, a chi-squared test was used to detect differences from an expected 50:50 sex ratio and also between the burned and control areas by assuming that the ratio observed on burned areas would be similar to their controls. The data for all communities combined indicates that there were nearly equal numbers of red-backed vole males and females on burned areas, but there was a significant preponderance of females on control areas. In contrast, male deer mice were more abundant on burned areas, while the male to female ratio was nearly equal on control areas (table 5). The data comparing the sex ratio observed in the burned area with that of its respective control was adequate only for red-backed voles. These data indicate that for all types combined, the sex ratio observed on burned areas was not significantly different from that observed on control areas.

Reproduction

Males were considered reproductively active if they had scrotal or ascending testes and females if they had medium or large nipples. The red-backed vole was the only species that showed evidence of

Table 3.—*Age class distribution on burned and control areas of three community types*

Community type	Area	Age class							
		Juvenile		Subadult		Adult		Unknown	
		Captures	Total captures	Captures	Total captures	Captures	Total captures	Captures	Total captures
		Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
				Red-backed vole					
Aspen-fir spruce	Burn	1	5	11	50	10	45	-	-
	Control	9	7	58	43	63	47	5	4
Jack pine	Burn	1	17	3	50	2	33	-	-
	Control	4	5	43	57	28	37	-	-
Black spruce-jack pine	Burn	-	-	1	33	2	67	-	-
	Control[1]	-	5	-	57	-	37	-	-
Total all types	Burn	2	6	15	48	14	45	-	-
	Control	13	6	101	48	91	43	5	2
				Deer mouse					
Aspen-fir spruce	Burn	3	100	-	-	-	-	-	-
	Control	17	47	19	53	-	-	-	-
Jack pine	Burn	5	71	2	29	-	-	-	-
	Control	3	75	1	25	-	-	-	-
Total all types	Burn	8	80	2	20	-	-	-	-
	Control	20	50	20	50	-	-	-	-
				Masked shrew					
Aspen-fir spruce	Burn	-	-	2	100	-	-	-	-
	Control	-	-	4	80	1	20	-	-
Jack pine	Burn	-	-	1	50	-	-	1	50
	Control	-	-	7	100	-	-	-	-
Total all types	Burn	-	-	3	75	-	-	1	25
	Control	-	-	11	92	1	8	-	-

[1]A control was not obtained, but due to similarities in the understory, values from the jack pine control were used for comparison.

Table 4.—*Mean body weight of the red-backed vole and deer mouse by community type and area*

Community type	Area	Red-backed vole			Deer mouse		
		Observations	Mean body weight	Standard error	Observations	Mean body weight	Standard error
		Number	*Grams*		*Number*	*Grams*	
Aspen-fir-spruce	Burn	22	19.4	0.9	3	14.7	0.3
	Control	112	20.8	0.5	28	15.9	0.3
Jack pine	Burn	6	17.7	1.0	7	15.4	0.8
	Control	73	20.0	0.7	4	15.1	0.8
Black spruce-jack pine	Burn	3	20.9	1.8			
	Control[1]	73	20.0	0.7			
All types combined	Burn	31	19.2	0.7	10	15.2	0.5
	Control	185	20.5	0.4	32	15.8	0.3

[1]A control was not obtained, but due to similarities in the understory, values from the jack pine control were used for comparison.

Table 5.—*Sex ratios of the red-backed vole and deer mouse on burned and control areas of three community types. A chi-squared test was used to compare the sex ratio with an expected 50:50 ratio, and the ratio on the burn with its respective control*

Community type	Area	Male	Female	Unknown sex	Total	Male	x^2 50:50 Ratio	P	x^2 Burn: Control	P
		Number				*Percent*				
		Red-backed vole								
Aspen-fir-spruce	Burn	12	10	0	22	55	-	-	-	-
	Control	46	85	4	135	35	11.611	[3].999		
Jack pine	Burn	2	4	0	6	33	-	-	-	-
	Control	33	41	1	75	45	.865	.648		
Black spruce-jack pine	Burn	1	2	0	3	33	-	-	-	-
	Control[2]	-	-	-	-	45	-	-	-	-
All types combined	Burn	15	16	0	31	48	.032	.143	1.270	.740
	Control	79	126	5	210	39	10.776	[3].999		
		Deer mouse								
Aspen-fir-spruce	Burn	3	0	0	3	100	-	-	-	-
	Control	19	15	2	36	56	.471	.507		
Jack pine	Burn	4	3	0	7	57	-	-	-	-
	Control	1	3	0	4	25	-	-		
Black spruce-jack pine	Burn	-	-	-	-	-	-	-	-	-
	Control[2]	-	-	-	-	-	--	-		
All types combined	Burn	7	3	0	10	70	-	-	-	-
	Control	20	18	2	40	53	.105	.254		

[1]The proportion of males was based on the total number of individuals for which sex could be determined.
[2]A control was not obtained, but due to similarities in the understory, values from the jack pine control were used for comparison.
[3]Significant at the 0.95 level of probability.

reproductive activity, thus the analysis was restricted to this species. For the aspen-fir-spruce and jack pine communities combined, the number of reproductively active males and females was equal at about one-fourth of the total population and similar between burned and control areas (table 6). The data comparing reproductively active individuals to the adult segment of the population was similar, except it amounted to about one-half of the adult population.

DISCUSSION

Population Characteristics not Related to Fire

The C.I. of 900 for red-backed voles, 240 for deer mice and 47 for masked shrews show that populations were high in control areas. Although methods varied, the highest C.I.'s reported from

other studies in northern Minnesota were either comparable or lower. For example, Beer *et al.* (1973) reported C.I.'s of 19 for red-backed voles, 8 for deer mice, and 5 for masked shrews, during the summer of 1969 in several different forest communities. In mature aspen-birch communities, Beer (unpublished data) found that for a period of 21 years, C.I.'s (per 1,000 trap nights) for red-backed voles ranged from 3 to 37 with an average of 11, and for deer mice they ranged from 16 to 135 with an average of 49. For a 4-year period after the Little Sioux Fire, Buech (unpublished data) obtained C.I.'s (per 1,000 trap nights) up to 243 for red-backed voles and up to 130 for deer mice. For a 4-year period in a mature jack pine stand, Ahlgren (1966) obtained data that indicated C.I.'s of up to 750 for red-backed voles and 350 for deer mice.

Further evidence that red-backed vole populations were high is suggested by the age class distribution. Krebs *et al.* (1969) noted that increasing and peak populations of *Microtus* are characterized by large adults. More than 40 percent of the red-backed voles captured in our study weighed more than 19 grams and 20 percent (8 percent males) weighed more than 25 grams. By comparison, during September in an increasing population of red-backed voles, Buech (1974) found few males more than 19 grams and none more than 25 grams. Thus, for this time of year, the proportion of large-sized adults on the Roy Lake Fire was high. In addition, one half of the adults showed signs of reproductive activity, and although none were pregnant, 7 percent of all captures were females weighing more than 30 grams. Thus, although they were reproductively active in early September, the lack of pregnancies indicates activity would probably cease by the end of September, which is similar to what Buech (1974) found. To summarize, the population of red-backed voles was high and contained many large-sized adults that were still reproductively active. Although breeding was near completion, the number of lactating females suggests that the population would increase when their litters entered the trappable population.

Although C.I.'s indicate that the deer mouse was abundant, there was a curious lack of adult-sized individuals and because none were reproductively active, little further increase would be expected during autumn. In contrast, in September during a population high, Buech (1974) found a large ratio of adult-sized individuals, some of which were still reproductively active.

The diversity and abundance of small mammals on the aspen-fir-spruce control was expected because of the vegetation structure and diversity.

Table 6.—*The number of males with scrotal or ascending testes and the number of females with medium or large nipples on the burned and control areas of three community types for the red-backed vole*

Community type	Area	Males			Females		
		Total	Scrotal testes	Scrotal testes	Total	Medium-large nipples	Medium-large nipples
		Number		*Percent*	*Number*		*Percent*
Aspen-fir-spruce	Burn	12	3	25	10	4	40
	Control	46	8	17	85	18	21
Jack pine	Burn	2	0	0	4	0	0
	Control	33	11	33	41	13	32
Black spruce-jack pine	Burn	1	1	100	2	1	50
	Control[1]			33			32
Aspen-fir-spruce and jack pine Combined (all ages)	Burn	14	3	21	14	4	29
	Control	79	19	24	126	31	25
Aspen-fir-spruce and jack pine combined (adults only)	Burn	4	1	25	7	4	57
	Control	36	17	47	55	31	56

[1]A control was not obtained, but due to similarities in the understory, values from the jack pine control were used for comparison.

Vegetation sampling in the shrub, herbaceous, and moss layers of the aspen-fir-spruce and jack pine control communities indicated major differences in species composition and density.[1] The biomass of shrubs and seedlings in the aspen-fir-spruce control was more than four times the amount in the jack pine control area. Similarly, herbaceous biomass in the aspen-fir-spruce control area was more than three times that in the jack pine control area. However, the jack pine control area supported a moss-lichen layer with twice the biomass of that found in the aspen-fir-spruce control. In both areas, though, the moss-lichen layer was the dominant component, after trees, in total biomass.

During a population low, Beer *et al.* (1973) found that small mammals were uniformly distributed among aspen-birch, birch, jack pine-birch, and jack pine communities. This suggests that the differences we observed between communities may not have existed if populations had been much lower. Data from other studies also suggest that mature jack pine communities are suitable for red-backed voles, although this may be expressed only during population highs (Ahlgren 1966, Sims and Buckner 1973, Krefting and Ahlgren 1974).

The discovery of a population of rock voles is particularly noteworthy. The existence of this species in Minnesota is known from a single specimen taken near Burntside Lake in St. Louis County (Swanson 1945, Handley 1954) and a recent discovery of a population north of Grand Marais along the Gunflint Trail (Timm 1974). Our specimens identify a second recent population in the State (Buech *et al.* 1977).

Impact of Fire on Small Mammal Populations

Studies of small mammal populations following wildfires and prescribed burns have revealed instances in which individuals survived the fire within the confines of the burn (Tevis 1956, Tester 1965, Lawrence 1966), escaped the fire by immigrating to unburned areas (Tevis 1956, Howard *et al.* 1959, Lawrence 1966), or died as a result of fire (Tevis 1956, Chew *et al.* 1959, Tester 1965). The survival of residents staying within the burn itself has been associated with the existence of small inclusions of unburned habitat (Tevis 1956, Lawrence 1966). Data provided by Lawrence (1966) and Howard *et al.* (1959) suggest that the conditional lethal temperature range is about 120 to 145° F, depending on the relative humidity. Other experiments by Lawrence (1966) suggest that animals can survive as long as burrow conditions permit vapor pressures below 40 mm Hg and if their burrows are at least 3 inches below the soil surface. Thus, these studies suggest that survival within the burn is contingent upon the uniformity, intensity, and duration of the burn with survival being greater where the burn is incomplete in fuels of low density and high moisture content.

Survival by emigration to unburned areas has been noted both through direct observation (Tevis 1956, Howard *et al.* 1959) and inference through the results of trapping (Tevis 1956, Lawrence 1966). However, these observations were made in comparatively small prescribed burns. In extensive wildfires, this strategy may be less successful for small mammals as evidenced by the number of carcasses found by Chew *et al.* (1959) in the extensive Malibou burn in southern California. Thus, the importance of emigration to survival of resident small mammals probably depends on the extent of the burn and the forward rate of spread.

The Roy Lake Fire occurred at the end of August during an extreme drought in aspen-birch-conifer communities. The fire was intense and entirely consumed the foliage and fine branches in tree crowns and organic material on the ground down to mineral soil, especially on the slopes and ridge tops. In spite of this, the variable topography permitted some portions to escape burning entirely or to burn only lightly, especially in depressions and lowland areas. This lack of uniformity was probably conducive to the survival of a segment of the prefire resident population of small mammals and to their continued postfire existence on the trapped sites.

The time interval between the end of the burn and the beginning of trapping was a little more

[1] *Siderits, Karl. 1977. Roy Lake Fire biological administrative study. Unpublished report on file at Superior National Forest, Duluth, Minnesota.*

than 1 week. This allowed little time for immigration, especially to interior portions of this large fire. However, it is possible that part of the postfire population was composed of individuals that moved in after the fire, or shifted their location within the burned area. This is suggested by the data for deer mice in the jack pine type, where they were more abundant on the burn than on the control area and where there was some suggestion that males and juveniles were more abundant on burned areas than would be expected. Thus the data may represent not only postfire survival, but may also reflect some other population adjustment factor that operated after the fire. These factor(s) however, did not statistically alter population attributes such as age class distribution, mean body weight, sex ratio, or the number of reproductively active adults from that observed in control populations, especially for red-backed voles. However, our sample size on the burned areas was often too small to detect any statistical difference.

The fire had a significant impact on the small mammal population, reducing it to an average of 16 percent of the prefire population. By comparison, Lawrence (1966) captured none on a large fire some 32 days after it was out (although tag returns indicated some did survive). Data provided by Cook (1959) indicate that 3 weeks after a large chaparral fire, the residual population was only about 2 percent in the grassland and 14 percent in brushland when compared to control populations. In smaller prescribed burns (up to 10 ha in size), residual populations have been as high as 50 percent of their controls (Spencer 1956, Tevis 1956, Fala 1975). Our data are of the same magnitude as those found in studies of large burns where immigration from adjacent unburned areas is not as extensive.

In the aspen-fir-spruce and jack pine communities combined, the population of the red-backed vole, an herbivore, was lowered more than that of the deer mouse or the masked shrew. This would be expected for a species whose primary food and cover had been eliminated by fire. In contrast, the higher postfire population of the masked shrew, an insectivore, was unexpected, because it seems that fire would reduce food and cover important to their survival in a manner similar to red-backed voles. However, the sample size was small and there is no literature to corroborate this observation. The population of the deer mouse, a granivore, was low on the aspen-fir-spruce burned area, only 8 percent of its control. In the jack pine community, however, their abundance on the burned area exceeded that of the control area. This can be explained by the postfire jack pine and black spruce seedfall data that estimated 68,000 viable seeds/ha in the aspen-fir-spruce burn and 484,000 viable seeds/ha in the jack pine burn .[1]

A severe reduction in herbivores and the invasion of granivores following fire has been reported (Tevis 1956, Cook 1959, Tester 1965, Ahlgren 1966, Sims and Buckner 1972, Krefting and Ahlgren 1974, Fala 1975). However, data provided by Ahlgren (1966), Sims and Buckner (1972), and Krefting and Ahlgren (1974) suggest that this will be transitory. Depending on outside population levels, red-backed vole populations should remain low and deer mouse populations should decline in the jack pine community until the end of the first or possibly second growing season when the ground vegetation recovers and begins to produce seed. Then, deer mice should increase and at the end of the third growing season red-backed voles should begin to increase. Habitat should remain more favorable for deer mice for about seven growing seasons, after which it should become more favorable for red-backed voles. The pattern in the aspen-fir-spruce community should be similar except the abundance of red-backed voles and deer mice should remain low until the end of the first or second growing season for deer mice and the third growing season for red-backed voles.

Because the Roy Lake Fire occurred in early fall, revegetation will not occur until the following spring. By this time, the lack of food and cover and winter mortality should reduce red-backed vole populations to even lower levels and they should remain low for several years. Thus, this species should not be a significant factor in the reforestation of any of the three communities, in spite of the high current population. Although the same may not be true for deer mice, the lack of vegetation, winter mortality, and the fact that reproductive activites for the year were complete should hold down their spring population. This would be important to natural reforestation of areas where seedfall was light. However, because seedfall in the jack pine and black spruce-jack pine communities was more than sufficient,

adequate moisture for germination and survival will probably control reforestation. In the aspen-fir-spruce community, where aspen vegetative reproduction is likely, deer mice will have little impact.

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1977. Small mammal populations after a wildfire in northeast Minnesota. USDA For. Serv. Res. Pap. NC-151, 8 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

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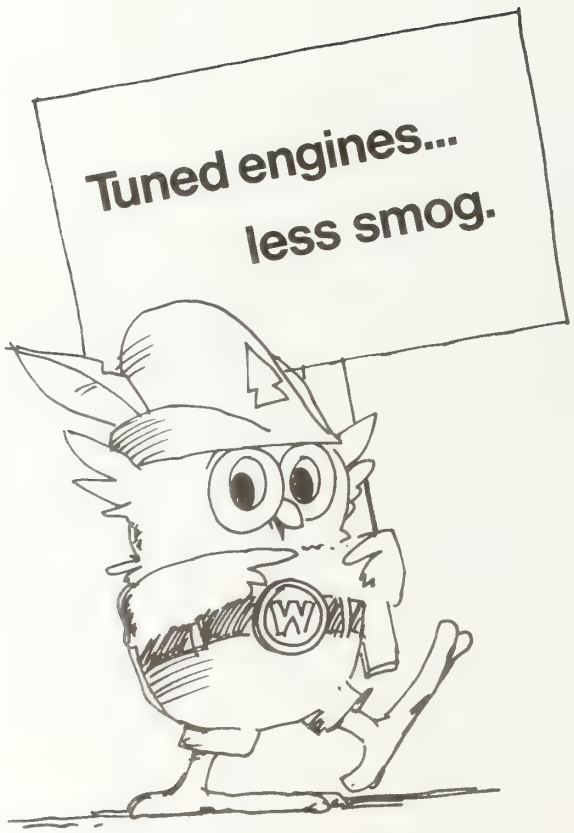
Small mammals were studied shortly after a large wildfire in northeast Minnesota. An average of only 16 percent as many small mammals were in three forest communities that had burned than were in comparable unburned areas. The greatest reduction was for the red-backed vole. An analysis of population attributes suggests that deer mice immigrated to the burned area. Small mammal succession and their impact on reforestation is predicted.

OXFORD: 153:(776). KEY WORDS: southern red-back vole, deer mouse, masked shrew, rock vole, least chipmunk.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Gnomonia Canker: shoot blight, and leaf spot of YELLOW BIRCH

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GNOMONIA CANKER, SHOOT BLIGHT, AND LEAF SPOT OF YELLOW BIRCH

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For a number of reasons it has been difficult to establish northern hardwood forests in the Great Lakes region that contain a stocking of yellow birch (*Betula alleghaniensis*) similar to that of the climax forests encountered by the early settlers (Tubbs 1969).Several factors that have contributed to the decline of yellow birch are competition with other tree species (Tubbs 1973), animal browsing (Graham 1954, Stoeckeler and Limstrom 1950), and a canker disease caused by *Diaporthe alleghaniensis* Arnold (Arnold 1967, 1970, Kessler 1971, Burton *et al.* 1969). In this paper I report on another fungus, *Gnomonia setacea* (Pers.) Ces. et DeNot., that affects yellow birch regeneration.

MATERIALS AND METHODS

To isolate the fungus, stem cankers were cut into fragments and surface-sterilized in undiluted commercial sodium hypochlorite bleach for 4 to 10 minutes. The canker fragments were then plated on a streptomycin-sucrose-yeast extract (30 ppm - 10 g - 2g/L) agar medium and incubated at 20 C for 1 to 2 weeks. Isolations from fruiting bodies were made by grinding them in sterile water and plating serial dilutions of the resulting spore-mycelial suspensions on the streptomycin-sucrose-yeast extract agar medium.

For germination studies spore masses were added to 100 ml of sucrose-yeast extract solution (10 g:2 g/L) and stirred with a magnetic stirrer for 15 minutes to disperse the spores. Serial dilutions were then made into petri dishes and spore concentrations determined. Percent germination was determined for 200 conidia scattered over at least 10 sites on each dish.

Plants were grown in a growth chamber for 2 months in agricultural perlite to which Knop's nutrient solution was added weekly. After 2 months the plants were inoculated and then watered with KCl solutions to create a moisture stress. Three KCl concentrations were used to create stresses of -5, -8, and -14 bars. Plants were again watered with KCl solutions at 3, 5, and 7 days after inoculation. Ten days after inoculation the KCl solutions were washed from the perlite substrate by repeatedly flushing water through the pots.

Leaves were inoculated by spraying sucrose-yeast extract solution (10 g:2g/L) containing dispersed conidia onto leaf surfaces with a plastic atomizer. Inoculated plants were kept at 100 percent relative humidity for 3 to 5 days and then moved to greenhouse benches for observation.

Stems from 5 to 15 mm in circumference were inoculated by applying drops of conidial suspension to stem wounds that had been made with scalpels, dissecting needles, pruners, long-nosed pliers, dry ice, heated nailsets, or by stem bending. Wounds were covered with moist cotton and aluminum foil. Stems were also inoculated with mycelia. Inoculations were made at internodes on the lower portions of main stems of seedlings. A tangential bark-flap wound was made with a scalpel and a piece of mycelial inoculum, which had been taken from the margin of a 3-day-old fungal colony, was inserted under the flap. Sterile moist cotton was then applied over the wound and covered with aluminum foil.

Field inoculations were also carried out. Each month from May to November 1972, 20 3-year-old yellow birches were inoculated by the scalpel-stem wound method near Hiles, in northern

Wisconsin. The following April, 20 additional trees were inoculated.

To obtain the perfect, perithecial stage, infected leaves with leaf spots were placed on moistened sphagnum in aluminum trays and covered with a 1 to 2 cm layer of moist sphagnum in October 1973. The trays were incubated at 2 C. Each month the leaves were examined for the presence of perithecia.

RESULTS

Distribution

Gnomonia setacea has been isolated from cankers on yellow birch seedlings throughout the commercial range of that tree in Michigan, Minnesota, and Wisconsin. Incidence of main stem girdling cankers in 12 hardwood stands surveyed in Wisconsin and Michigan ranged from 7 to 68 percent (average 28 percent). Recovery rate of the fungus from cankers has ranged from 6 to 69 percent (average 21 percent). The fungus is readily isolated from acervuli on leaf spots during spring and summer. In the fall conidial production from acervuli diminishes and recovery of the fungus from leaves becomes more difficult.

Symptoms

Incipient cankers are confined to the outer bark. As cankers develop, inner bark and even wood may become affected and discolor. Cankers are blackish and may appear sunken in later stages due to a combination of cell collapse and growth of healthy tissues surrounding the cankers (fig. 1, p. 6). In the spring, cankers may girdle the new terminal shoots and cause a shoot blight stage of the disease. Such stems often develop a characteristic "shepherd's crook" bending. Canker's on older wood sometimes completely girdle stems during summer-particularly during drought periods (fig. 2, p. 6). The first indication of imminent summer stem girdling is the development of foliar chlorosis. Chlorosis is then followed by foliar wilting. In some cases cankered stems heal. When this happens, the necrotic tissues are sloughed away and a lenticular gall develops (fig. 3, p. 6;4). Leaves with leaf spot infections generally abscise within 2 weeks. Because of this rapid abscission, it is seldom that more than a few spotted leaves be found on a tree at any given time. The spots brown, vary in shape, and are sometii delimited by major veins (fig. 5, p. 6). Chlor zones surround the spots, particularly the la ones. Size of the spots range from 3 mm to sev centimeters.

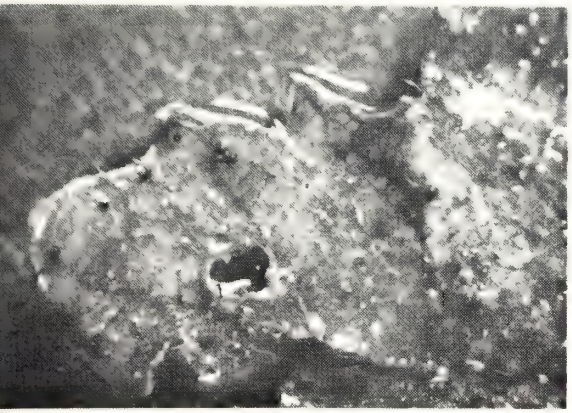
The shoot blight canker symptoms of ye birch canker disease caused by *Diapo alleghaniensis* Arnold and described by Ar (1967) cannot be distinguished from those cau by *G. setacea.*

Figure 4.—*Healed canker.*

The Causal Organism

The perithecial perfect stage develop diseased leaves after the leaves have been sh the fall. When leaf-spotted leaves collected i and September, 1973, were incubated at moist sphagnum or perlite, perithecia were found on them in early January. The peri were generally more numerous on the dorsa

the ventral leaf blade surface (fig. 6). However, leaves were incubated dorsal side up, so this y have affected perithecial distribution.



ıre 6.—*Perithecia that have developed on a fallen leaf.*

Perithecia developed on or close to the leaf ts—more near the spot margins than in the t center. Fewer perithecia were found on ioles presumably because leaf spots were not tiguous with petioles on many leaves.

The ascocarps develop within the leaf tissues. the ascocarps enlarge they tend to erupt ough the host tissue and become partially osed. In some cases only the ostiole is visible. the leaf tissue decays, more and more of the ocarp is exposed until finally it appears to be ting on the leaf surface.

Perithecia were 166 to 410 µm wide and 154 to µm high and their rostrums ranged from 41 to µm long and from 31 to 74 µm wide. Asci asured 5 to 8 by 20 to 29 µm and were cylindric clavate with an evanescent stalk and unituni- e wall that was conspicuously thickened at the x where a refractive ring surrounds the apical e. The ascus wall was difficult to see even with aid of stains or phase contrast microscopy (fig. Ascospores were 1.2 and 2.4 µm wide by 8.4 to 6 µm long, two-celled, hyaline with thin-walled endages at the ends, cylindrical, tapered htly at the ends, and were straight to slightly ved (fig. 8).

Figure 7.—*Asci.*

Figure 8.—*Ascospore.*

The perfect stage is *Gnomonia setacea* (Pers.) Ces et DeNot (table 1). This identification is based largely on the size of the perithecia, asci, and ascospores and on the presence of evanescent appendages at both ends of ascospores. *Gnomonia setacea* and *G. betulina* Vleugel, are the only *Gnomonia* species that have been reported on *Betula* spp. that have small ascospores bearing evanescent appendages. Ascospores of *G. betulina,* however, are much larger (Vleugel 1917) than those of *G. setacea.*

The acervulus imperfect stage develops on leaf spots (fig. 9, p. 7) and on stem cankers during the growing season. On the leaf tissue the acervuli develop subcuticularly (fig. 10). Phialophores are

Table 1.—*Comparison of the perithecial stage of yellow birch fungus with* Gnomonia setacea *of other authors*

Authority	Perithecial width	Asci	Ascospores	Hosts
		μm		
		G. SETACEA		
Kessler	166-410	20-29 by 5-8	8.4-14.6 by 1.8-2.4	*Betula alleghaniensis*
Saccardo 1882	150-300	30-40 by 6-9	14-15 by 1.5-2	*Quercus, castanea, Acer, Crataegus Betula, Alnus, Corylus*
Ellis & Everhart 1892	200-300	30-40 by 6-9	12-16 by 1.5-2	*Quercus, Castanea,* and other hardwoods
Rabenhorst 1887	200-300	30-40 by 6-9	14-16 by 1.5-2	Various tree and shrub species
Muller & von Arx 1962	200-400	30-40 by 6-9	14-16 by 1.5-2	Various tree and shrub species
		G. SETACEA f. *ALNI*		
Vleugel 1911	--	23-31 by 5-10 mature 57 by 13	10-13 by 1.5-2	*Alnus incana, A. borealis*
Klebahn 1918	140-180	25-30 by 6	11-13 by 1.5-1.7	
		G. SETACEA f. *BETULAE*		
Vleugel 1911	--	26-29 by 6-10	14 by 2.5	*Betula* sp.

Figure 10.—*Cross-section of acervulus on leaf with intact host cuticle (arrow).*

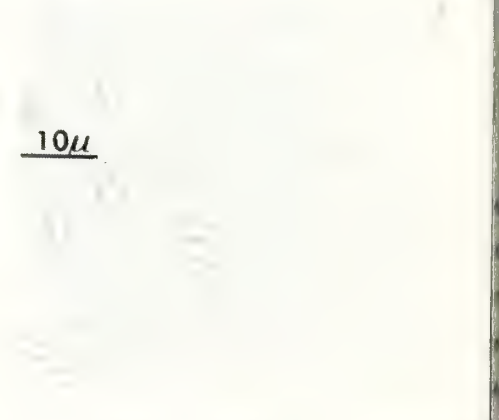


Figure 11.—*Swollen conidia prior to germina Notice different shapes.*

densely crowded. The conidia vary in shape and range from rod-shaped to allantoid (fig. 11). Prior to germination conidia imbibe water and increase their size markedly.

In culture the fungus develops zonate colonies with a cottony-feathery aerial mycelium (fig. 12, p. 7). Acervuli are produced abundantly in culture, particularly within the agar medium (fig. 13, p. 7).

Disease Cycle

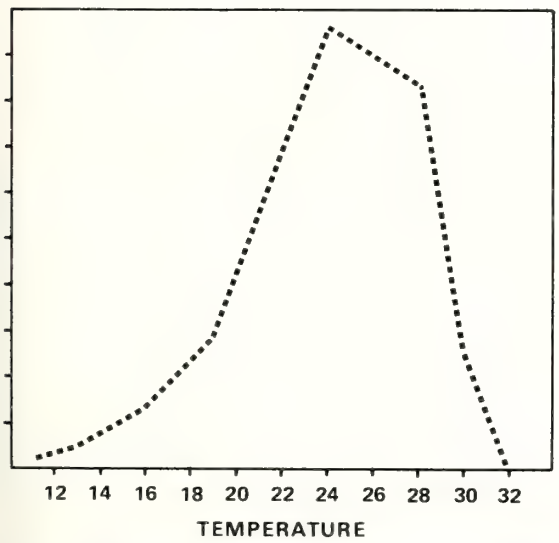
Conidia require nutrients to germinate. Sucrose-yeast extract solutions, in particular, supported good germination. When nutrients present in sucrose-yeast extract were tested individu results were extremely variable. In some ex ments the addition of sucrose to distilled increased the percentage of germination alth its addition had little effect in other experim Nitrogen sources, in particular asparagine hanced germination. Conidia sometimes sw and developed slight germ tube-like prot ances in distilled water but usually were unal develop further.

At temperatures of 7 C or less, more tha hours were required for conidial germ tub reach a length capable of penetrating host (table 2.). After 24 hours, growth was limited degrees or lower, moderate at 16 degrees extensive at temperatures from 19 to 3

mal temperatures for early germ tube nsion were 25 to 28 C. After 48 hours growth still limited at 7 degrees or lower, moderate at egrees, and extensive at temperatures from 30 C (fig. 14). Germ tubes developing at 30 C n coiled or curled abnormally. Little or no n tube development occurred at 32 C.

e 2.—*Development of conidial germ tubes at temperatures from 1 to 30 C*

Temperature (C)	Time (hours) 24	48	108
		μm	
1	0	3	11
7	0	7	>200
12	3	13	>400
13	5	165	>600
16	13	340	>600
19	29	>600	>600
22	55	>600	>600
25	96	>600	>600
28	83	>600	>600
30	26	113	>600



re 14.—*Relation of conidial germ tube length to temperature. Incubation time 24 hours.*

self-inhibitor severely restricts spore germ-on at conidial concentrations greater than 50 es/mm^3 (fig. 15). Spores did not germinate at percentage rates unless they occurred in entrations of 20/mm^3 or less. At conidial entrations of 800 spores or more per mm^3, es failed to germinate. Attempts to wash the

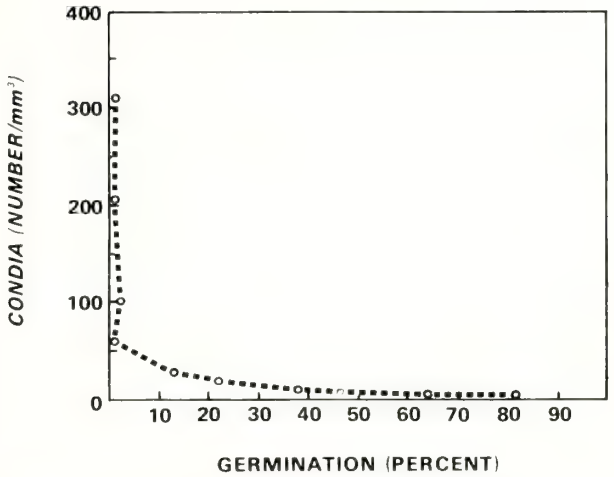


Figure 15.—*The effect of conidial concentration on germination.*

germination inhibitor off the spores were unsuccessful.

Leaves and petioles were more susceptible to conidial infection than were buds and stems. Buds were the most resistant part of the plant (10 percent successful infections compared to 98 for leaves, 75 for petioles, and 25 for stems). After 10 days leaf spot size on inoculated apical leaves averaged 10 by 8 mm. Canker development was greater at nodes than at internodes; 5 of 15 inoculations at nodes resulted in stem girdling cankers and comparable inoculations at internodes produced no girdling cankers.

All wounds that ruptured the bark could be infected (see tabulation below).

Wound type	Percent stem circumference affected		
	Inoculated wound (A)	Control wound (B)	Pathogen affect (A-B)
Needle	50	13	37
Scalpel scrape	33	0	33
Heated nailset	52	50	2
Knife cut	49	21	28
Dry ice and needle	39	28	11
Dry ice and scalpel scrape	56	39	17
Dry ice	36	37	-1
Dry ice and knife cut	66	57	9
Nailset	49	40	9
Stem bending	50	0	50

Size of wound was not as important as type of wound; needle wounds developed comparatively much larger cankers than tangential knife cuts. When an adjustment is made for wound size, canker development arising from the invasion of *Gnomonia setacea* can be determined and compared for different types of stem wounding.

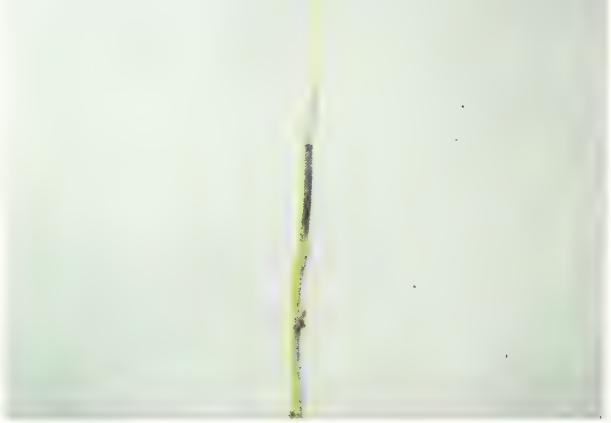


Figure 1.—*Canker on young seedling (dark area).*

Figure 3.—*Healing canker sloughing off ou bark.*

Figure 2.—*Effects of stem girdling by a canker during a summer drought.*

Figure 5.—*Leaf spots.*

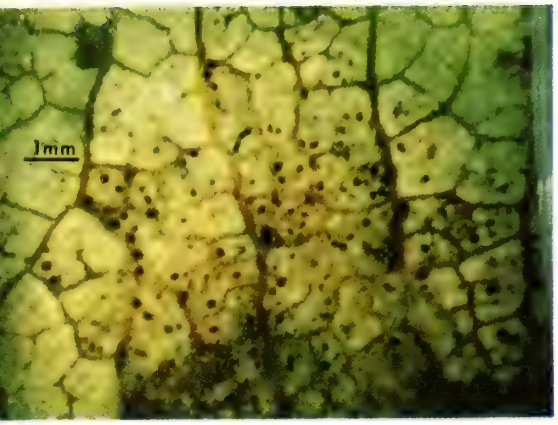


Figure 9.—*Acervuli on leaf spot.*

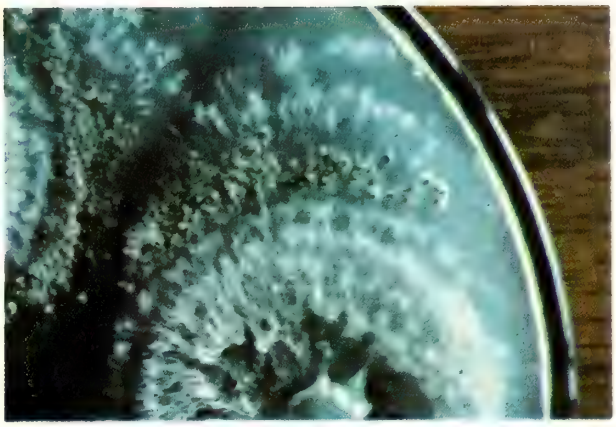
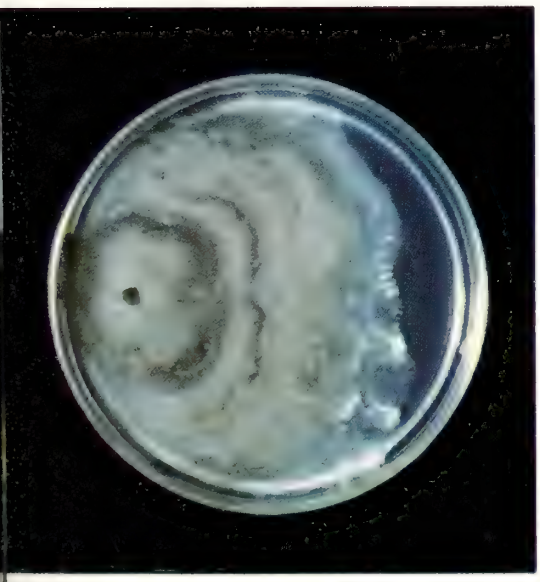


Figure 13.—*Masses of conidia produced in acervuli that developed in agar plate culture.*



ıre 12.—*Growth of typical isolate of* Gnomonia tacea *on sucrose-yeast extract agar medium.*

Wounds that did not rupture the bark, such as those made by dry ice or hot nailset applications to stems, did not become colonized, even though more than a third of a stem's circumference was injured in creating such wounds. Some wounds, such as dry ice injury followed by a knife cut into the wounded area, developed into large cankers. When the correction was applied for wounding injury, the contribution of *G. setacea* to the enlargement for such wounds was low. The wounds that enabled *G. setacea* to influence canker size the most were stem needle wounds and stem bending. If bent stems were inoculated, about half of them became girdled at the point of bending (fig. 16, p. 9). Stems that were clipped and inoculated where they were cut off died back to the first live bud. Uninoculated clipped stems did not die back.

Fresh stem wounds were more susceptible to infection than older wounds (fig. 17, p. 9). Stem wounds gradually became less susceptible in the week following wounding.

Stem age was not as important as the degree of stem lignification in influencing susceptibility. Succulent stems were more susceptible to cankering than lignified ones. When trees were inoculated at three stem locations, all inoculations of

Figure 18.—*Inoculation on current seasc growth (upper arrow) resulted in stem girdl and wilting of foliage. Moderate-sized can (upper inset) developed after inoculation 2-year-old portion of stem. Small canker (lo inset) developed after inoculation of 5-year stem.*

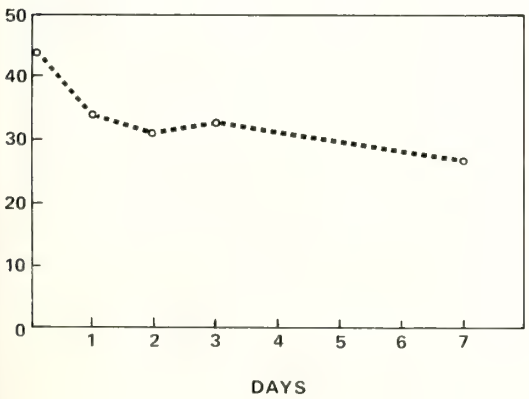
Figure 22.—*Ascospore inoculation of petiole s Note canker development (arrow).*

succulent current season's terminal growth res ed in stem girdling cankers, basal stem inoc tions (stem age 5 years) resulted in small cank and inoculations of 2-year-old stems resulte moderate-sized cankers (fig. 18, above).

Creating moisture stress conditions in in lated plants irrigated with potassium chlori Knop's solutions increased the size of basal s cankers (see tabulation below).

Osmotic pressure	Stem circumference cankered
(Bars)	(Percent)
0	36
-5	44
-8	60
-14	72

re 16.—*Plants on left were inoculated with nidia after their stems were bent. Plants on e right had their stems bent but were not oculated.*



re 17.—*Effect of age of wound on canker development.*

Foliar moisture stress symptoms also developed. All foliage on -14 bar treated trees (severe moisture stress) and most of the foliage of the -8 bar treated trees became brown. Foliage of -5 bar treated trees (moderate moisture stress) was discolored at the leaf margins.

Gnomonia setacea grows best at temperatures from 20 to 26 C but it is capable of slow growth at temperatures of 1 to 10 C on a sucrose-yeast extract agar medium. At a temperature of 32 C growth is restricted and at 34 C growth does not occur (fig. 19). When stems are inoculated with the fungus in the spring, more canker development occurs at moderate temperatures than at low temperatures (table 3.). When inoculations were conducted on dormant birch during mid-winter, however, plants kept chilled at 2.5 C developed larger cankers than did inoculated plants transferred immediately to a greenhouse environment (fig. 20).

Monthly inoculations of yellow birch nursery stock planted in a northern hardwood shelterwood forest situation in northern Wisconsin revealed that the stems were most susceptible during June (fig. 21). Susceptibility decreased as the growing season progressed and by October the stems were resistant. Comparative inoculations made with *Diaporthe alleghaniensis* indicated that the two fungi followed a similar seasonal susceptibility pattern.

The most common sources of conidial inoculum are acervuli that develop on leaf spots during spring and summer. Although leaf spotting of sawtimber-sized yellow birch is generally not severe, the overstory position of these birch assure good conidial spread from their spotted leaves to smaller yellow birch beneath them. Acervuli also develop on cankers and blighted shoots, and conidia from these sources may contribute to the numerous multiple infections encountered on stems of natural seedlings. Conidial production from acervuli on leaf spots diminishes in the fall and by late October has virtually ceased. Leaves with leaf spots soon abscise and fall to the ground. Perithecia develop on fallen leaves and completely formed ones (but without asci) have been found as early as the end of October. When perithicia-containing leaf spots were incubated overwinter at 2 C on moistened sphagnum or perlite, mature ascospores did not form until April.

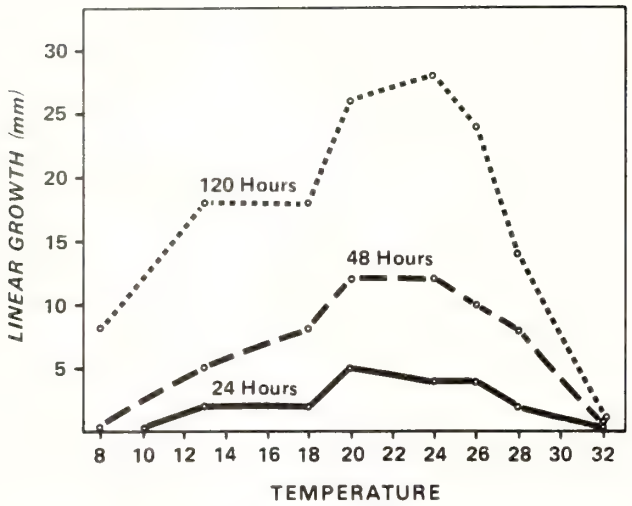


Figure 19—*Relation of linear growth* in vitro *to temperature.*

Table 3.—*Effect of chilling inoculated dormant stock on the development of cankers in June*
(In percent of stem circumference cankered)

Inoculum incubation temperature (C)	Plant treatment after inoculation: Planted and transferred to greenhouse	4 weeks at 5 C	4 weeks at 2.5 C
5	45	26	28
15	48	30	28
25	58	33	32
Average	50	30	29

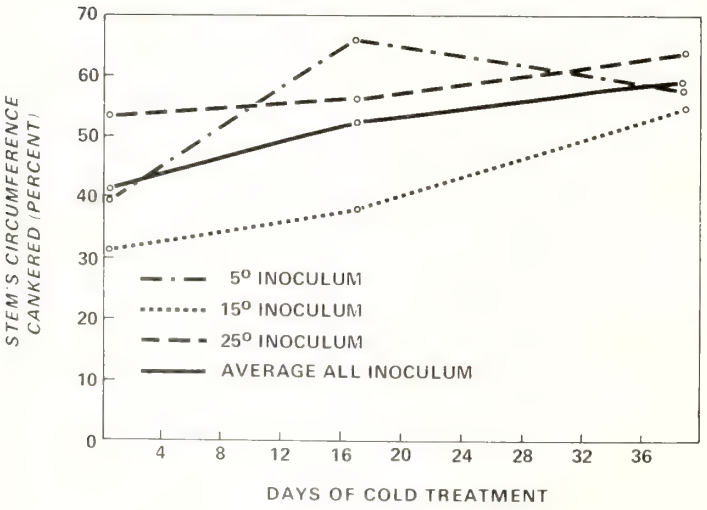


Figure 20—*Effect of length of chilling (2.5 C) dormant yellow birch on the development of stem cankers arising from inoculation in January.*

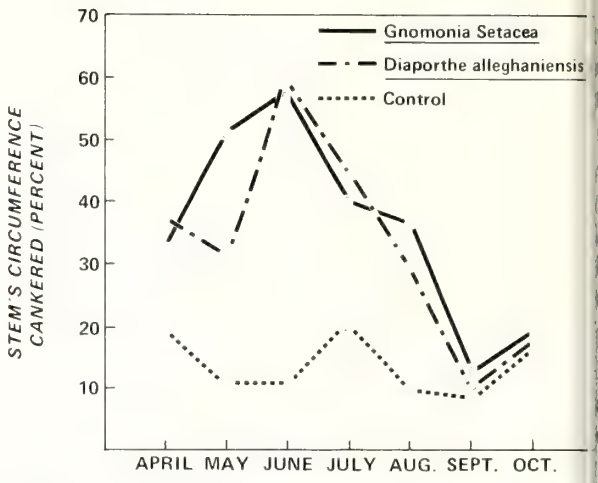


Figure 21.—*Seasonal susceptibility of yell birch to cankering by* Gnomonia setacea a Diaporthe alleghaniensis.

DISCUSSION

The link between the leaf spot phase of t disease complex and the canker and shoot blig phases was not established until the fall of 19 Prior to that time the primary source of spring a fall inoculum was thought to be conidia. With t discovery of the ascospore stage it now appe that ascospores are primary inoculum for st cankers that appear in the spring (fig. 22, p. 8

Self-inhibition of conidial germination serves a mechanism to limit germination to situatio where conidial concentrations are low. In additi the conidia require nutrients to germinate. Wou and leaf surfaces provide adequate nutrients support conidial germination and subsequent h infection. Self-inhibitors and nutrient requi ments thus tend to enhance germination succ in situations favorable to infection.

When leaves become infected, they so develop an abscission layer and drop to t ground. This happens even in cases where a sm infection spot develops at the distal end of t leaf. Apparently fungal infection of the l initiates the production of a potent toxin which some way initiates premature leaf abscission.

Cankers and shoot blights caused by *Gnomo setacea* and *Diaporthe alleghaniensis* cannot visually distinguished. Indentification requi examination of fruiting bodies or isolation obtain the causal agents in pure culture (Kess 1976). In a few cases both fungi have been isolat

the same canker. Artificial inoculations of wounds with both fungi indicated, however, the two fungi have little synergistic effect.

hough Vleugel (1911) described a form *ae* of *G. setacea,* it was based solely on rence on *Betula* sp. (table 1). Until host e studies have been conducted with isolates cted from several hosts, the form *betulae* nation should not be used.

e name of the imperfect stage of this fungus *lindrosporella microsperma* (Peck) Petr. (von 970). It was first described by Peck (1883) as *oria microsperma* (Peck). However, because conidia were not septate, *Septoria* was an rect designation of the imperfect stage. Davis), therefore, renamed it *Sacidium micro-num* (Peck). The same year Saccardo (1915), ut mentioning either *Septoria microsperma cidium microspermum,* named the imperfect *Gloeosporium betulae-luteae* Sacc. et n. The genus *Sacidium,* based on an rfectly described type species, is not valid. led Petrak (1924) to rename the fungus *drosporella microsperma* (Peck) Petr. Pe-s name for the imperfect stage was upheld by Arx in 1970. Von Arx considers the genus *osporium* to be too heterogenous to be valid onger. So if his concept of *Gloeosporium* is ved, Saccardo and Dearness' name for the us, *G. betula-eluteae* should not be used. I e with von Arx and, therefore, have used the e *Cylindrosporella microsperma* (Peck) Petrak he imperfect stage.

ds were more resistant to infection than were es, stems and petioles. In nature, cankers appear around dormant buds in the spring. ever, because artificial inoculation studies aled that buds are comparatively resistant to tion, the natural cankers at buds may arise petiole or petiole scar infections.

nkering of main stems often results in stem ing, a loss of apical dominance, and feration of lateral branches (figs. 23 and 24). shy'' birch of this type tend to lose their nant position in the reproductive layer of the t and are frequently overtopped by sur-ding vegetation. In some cases stems healed selves by sloughing off cankered bark tissue, h resulted in a lenticular-shaped gall (fig. 4). galls were common on birch seedlings in ral stands.

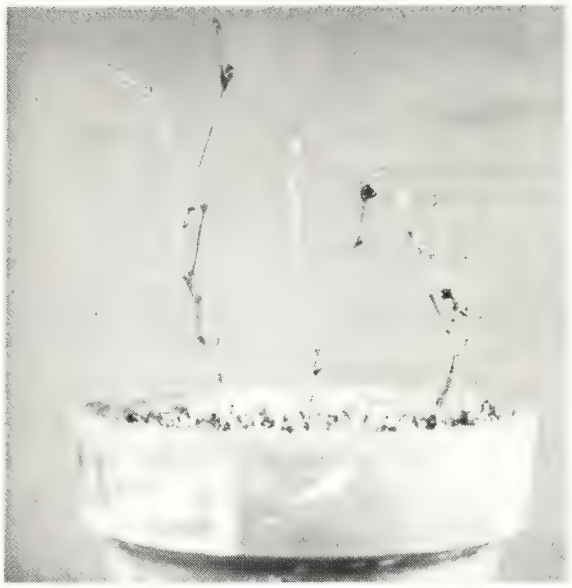


Figure 23.—*One-year-old dormant birch seedlings. Lateral branches developed after canker girdled main stems.*

Figure 24—*Three-year-old birch. Lateral branches developed after canker girdled main stems.*

FOREST MANAGEMENT IMPLICATIONS

Cankering and shoot blight are most serious on yellow birch seedlings with stem diameters less than 2 cm. By maintaining optimal growing conditions, the years of small seedling susceptibility can be reduced to 3 to 5 years. Seedlings growing on poor sites or subjected to unfavorable growing conditions such as drought or competition are much more likely to become infected and will remain susceptible for many years.

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Nature is beautiful...leave only your footprints.

DA FOREST SERVICE
SEARCH PAPER NC-153

morphology of jack pine and tamarack needles in dense stands

by: Terry F. Strong
J. Zavitkovski

NORTH CENTRAL FOREST EXPERIMENT STATION
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MORPHOLOGY OF JACK PINE AND TAMARACK IN DENSE STANDS NEEDLES

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Studies of biomass production in forest stands require measuring the leaf area of sample trees. In order to increase the precision of biomass estimates for our research in Wisconsin, we carried on a preliminary study to find out whether jack pine *(Pinus banksiana)* and tamarack *(Larix laricina)* needles differed in shape and size from one part of the crown to another. The results of this study are reported here.

Techniques used for determining leaf area of coniferous species are more complex than those for broadleafed species. Several methods have produced satisfactory estimates (Kozlowski and Schumacher 1943, Barker 1968, Balderston 1972, and Drew and Running 1975). The method used in this study was similar to that used by Madgwick (1964) and Harms (1971). The needle surface is expressed as a function of length and circumference measured at three points along the needle. The advantage of such a method is that it accounts for the irregular shape of the needle, and it is as precise as other methods as well as quicker.

METHODS

Needles were collected from 6-year-old jack pine and tamarack trees planted at spacings of 9 by 9, 12 by 12, and 24 by 24 inches. Two codominant trees were selected from each plot for a total sample of six trees of each species. Needle samples were collected in the upper, middle, and lower thirds of the crowns. Collections from jack pine trees included single needles from both the current and previous years. The sample from tamarack trees included single needles from current shoots and needles from whorls on lateral spurs.

One needle from each crown level was chosen at random and divided into four parts by cutting through the middle and removing 1/6 of the total needle length from each end (fig. 1). Magnified cross sections were photographed jointly with a stage micrometer used as a scaling device. The circumference of each needle section was then measured on the photograph with a linear map measuring device and adjusted to a real value. The surface area (S) of each needle was obtained as follows:

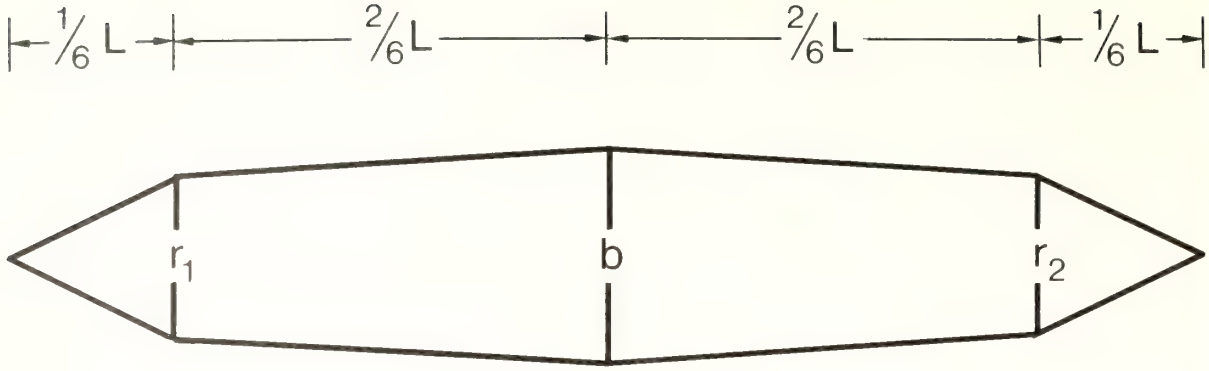
$$S = \frac{L}{12}(4b + 3r_1 + 3r_2) \qquad (1)$$

where L is the needle length and b, r_1 and r_2 circumferences of the middle and two end cross sections, respectively. The discrepancy between L and the correct slanted needle length averaged less than 0.3 percent and was neglected in the equation (1).

The length and dry weight were determined from a second sample of five needles collected at each crown level. The needles were dried at 70C for 48 hours and weighed to the nearest 0.1 mg.

Allometric relations were established between needle length and needle surface area and between needle length and needle dry weight. These two regressions were consolidated into one relating needle surface area to needle dry weight. This equation was validated on a small sample of needles for which surface area and dry weights were obtained on identical needles. Needle surface area was obtained in the same way as described earlier.

Curvilinear relations between the original values of needle length and surface area or dry weight, and between needle surface area and dry weight were linearized by logarithmic transformation (i.e., allometric model) and data fitted by the least square method. One additional advantage of the logarithmic transformation was normalization of variance of the data. To account



r_1 and r_2 ..... circumference of the ends $\frac{2}{3}$ the length from the middle

b ..... circumference of the middle

L ..... length

Figure 1. – *Model of needle surface area determination.*

for the inherent bias when values are retransformed from allometric regressions back into arithmetic units, correction factors were calculated according to Baskerville (1972). All statistical tests were performed using the 0.05 level of significance.

RESULTS

Jack Pine

The six jack pine trees ranged from 3.2 to 3.5 m in height and from 25 to 36 mm in d.b.h. Since no differences were apparent in relations between needle characteristics and tree size or between the 1974 and 1975 samples, all data were pooled for the analysis.

Needle lengths (L) and surface area of the needles used to determine surface area ranged from 18 to 62 mm and 46 to 211 mm^2, respectively (fig. 2). The allometric regression was:

$$\ln S = 1.46 (\ln L) - 0.63; R^2 = 0.97, S_{y.x} = 0.08$$
$$\text{Correction Factor} = 1.003 \quad (2$$

Needle lengths and dry weights (DW) of the secon needle sample ranged from 21 to 68 mm and from 1.0 t 21.2 mg, respectively (fig. 3). The formula for estimatin needle dry weight was:

$$\ln DW = 2.02 (\ln L) - 5.30; R^2 = 0.92, S_{y.x} = 0.18$$
$$\text{Correction Factor} = 1.016 \quad (3$$

The allometric regression relating needle dry weight an needle surface area, obtained by consolidating equatio (2) and (3) was:

$$\ln S = 0.72 (\ln DW) + 3.20 \quad (4$$

The sample needles used for validating the consol dated regression ranged from 20 to 61 mm in lengt from 37 to 202 mm^2 in surface area, and from 2.0 t 20.4 mg in dry weight. The measured and estimate values of surface area were not significantly different (= 0.05). The allometric regression based on the valid tion sample was:

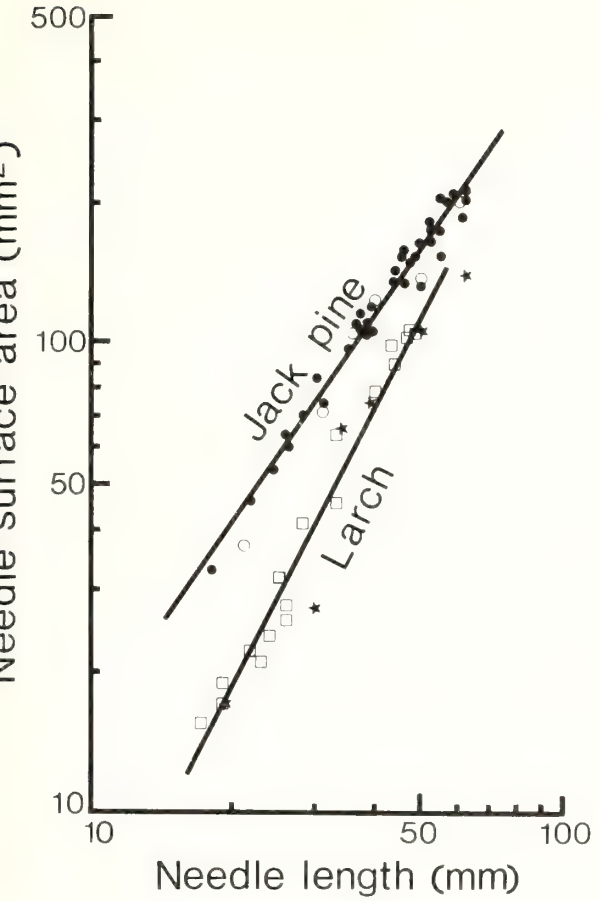


Figure 2. — *Allometric relation between length and surface area in jack pine (•) and larch (□) needles. Needles used for validation of the model are shown (○) for jack pine and (*) for larch.*

$$\ln S = 0.72 (\ln DW) + 3.14; R^2 = 0.99; S_{y.x} = 0.09$$
Correction Factor = 1.004 (4b)

Tamarack

The six tamarack trees ranged from 4.0 to 4.6 m in height, and from 21 to 33 mm in d.b.h. Needle values for individual trees were pooled because they showed no relation to tree size.

Sample needles used for surface area determination ranged from 19 to 49 mm in length and from 16 to 107 mm^2 in surface area (fig. 2). The allometric regression was:

$$\ln S = 2.03 (\ln L) - 3.15; R^2 = 0.97, S_{y.x} = 0.13 \quad (5)$$
Correction Factor = 1.001

Needle length of the second sample ranged from 17 to 52 mm and the dry weight from 0.4 to 7.6 mg. The allometric regression for needle dry weight was (fig. 3):

$$\ln DW = 2.98 (\ln L) - 9.52; R^2 = 0.96, S_{y.x} = 0.20$$
Correction Factor = 1.020 (6)

The allometric regression relating needle dry weight and surface area, obtained by consolidating equations (5) and (6), was:

$$\ln S = 0.68 (\ln DW) + 3.20 \quad (7a)$$

The sample needles ranged from 19 to 63 mm in length, from 17 to 138 mm^2 in surface area, and from 0.7 to 9.7 mg in dry weight. These values were not significantly different from values predicted from equations (5), (6), and (7). The allometric regression based on the validation sample was:

$$\ln S = 0.71 (\ln DW) + 3.12; R^2 = 1.00, S_{y.x} = 0.06$$
Correction Factor = 1.002 (7b)

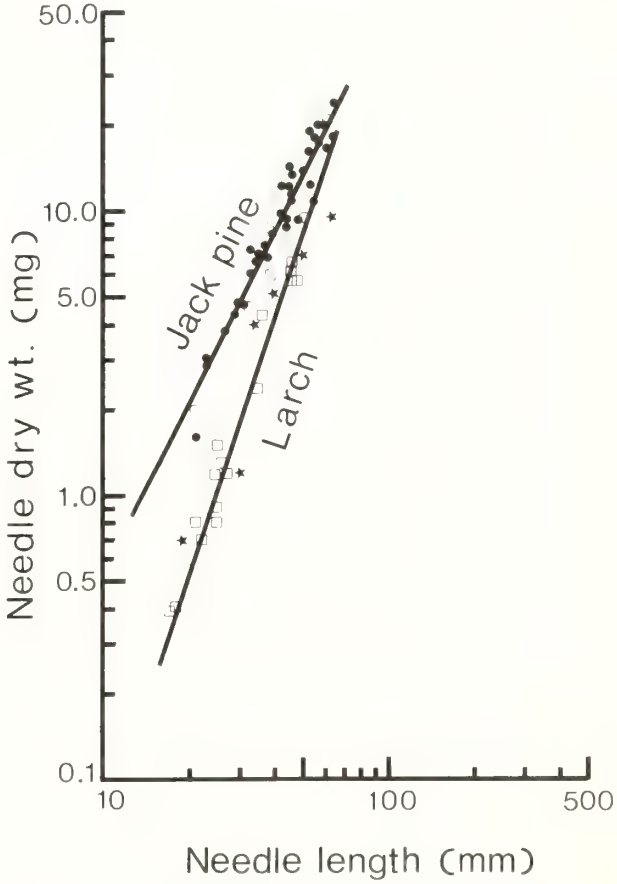


Figure 3. — *Allometric relation between length and dry weight of jack pine (•) and larch (□) needles. Each point represents five needles. Needles used for validation of the model are shown (○) for jack pine and (*) for larch.*

Effect of Crown Position on Needle Morphology

Lengths, surface areas, and dry weights of individual needles of both species were strongly affected by their location in the crown. Needles from the lower third of the crown were consistently, and in most instances significantly, shorter and had significantly smaller surface areas and dry weights than needles from the upper third of the crown (tables 1 and 2). Lengths, surface areas, and dry weights of needles collected from the middle third of the crown were intermediate.

The differences resulting from the position in the crown were greater in samples collected from dense plantations, especially in magnitude of surface areas and dry weights. For example, dry weights of 1975 jack pine needles from the 9- by 9-inch plantation averaged 19.2 and 3.1 mg for the upper and lower thirds of the crown, respectively—a ratio of 6.2. The ratio was 5.2 for the 12- by 12-inch plantation and only 1.9 for the 24- by 24-inch plantation. The corresponding ratios for the 1974 jack pine needles were less diverse—2.3, 2.2, and 1.3—and for tamarack 7.3, 17.6, and 6.2

The relation of needle size to position in the crown also held for specific needle area. For jack pine needles

Table 1. — *Last- and current-year's length, surface area, and dry weight of jack pine needles (mean length and dry weight are based on 10 determinations, mean surface area on 2 determinations)*

Spacing : Position in crown : (third)	Mean length				Mean surface area				Mean dry weight			
	1974		1975		1974		1975		1974		1975	
	mm	*SD*[1]	*mm*	*SD*	*mm²*	*SD*	*mm²*	*SD*	*mg*	*SD*	*mg*	*SD*
9 x 9"												
Upper	[2]54.2[a]	3.4	58.3[a]	2.1	164.5	15.6	204.7	6.8	18.0[a]	3.7	19.2[a]	1.3
Middle	49.4[a]	4.9	27.6[b]	1.1	126.9	32.8	61.5	2.0	15.2[a]	5.5	4.1[b]	0.4
Lower	36.8[b]	3.9	25.6[b]	5.2	112.9	3.5	58.7	36.4	7.7[b]	1.7	3.1[b]	1.7
12 x 12"												
Upper	54.2[a]	10.4	49.6[a]	8.4	171.8	54.9	156.4	5.1	18.9[a]	5.2	15.0[a]	3.0
Middle	41.8[a]	9.2	32.6[b]	3.6	136.1	45.7	83.5	19.5	10.6[ab]	3.5	5.9[b]	1.6
Lower	39.2[a]	7.4	23.1[c]	0.8	106.4	46.4	49.7	5.4	8.5[b]	2.8	2.9[c]	0.3
24 x 24"												
Upper	50.7[a]	3.8	54.6[a]	9.6	156.6	23.2	170.8	25.8	12.2[a]	0.9	15.7[a]	2.7
Middle	51.4[a]	9.8	43.0[b]	2.0	190.7	13.5	123.8	25.8	13.4[a]	3.9	9.2[b]	0.6
Lower	45.8[a]	9.4	43.2[b]	5.9	130.4	34.0	124.5	9.1	9.2[a]	1.9	8.1[b]	1.6

[1]SD = standard deviation.

[2]Within each spacing and year, means followed by the same letter are not significantly different (p = 0.05).

Table 2. — *Length, surface area, and dry weight of tamarack needles (mean length and dry weight are based on 10 determinations, mean surface area on 2 determinations)*

Spacing : Position in the crown : (third)	Mean length		Mean surface area		Mean dry weight	
	mm	*SD*[1]	*mm²*	*SD*	*mg*	*SD*
9 x 9"						
Upper	[2]41.0[a]	6.2	95.3	9.7	5.85[a]	1.34
Middle	25.2[b]	3.1	38.9	10.3	1.20[b]	0.42
Lower	22.7[b]	3.4	23.1	6.2	0.80[c]	<0.01
12 x 12"						
Upper	44.7[a]	4.5	103.4	5.7	7.05[a]	0.78
Middle	23.7[b]	1.9	32.8	13.2	0.95[b]	0.35
Lower	18.2[c]	0.9	16.3	0.8	0.40[c]	<0.01
24 x 24"						
Upper	45.2[a]	4.5	92.4	19.8	5.85[a]	0.21
Middle	30.8[b]	5.0	44.6	25.9	1.85[b]	0.78
Lower	24.2[c]	3.7	21.5	0.2	0.95[c]	0.35

[1]SD = standard deviation.

[2]Within each spacing, means followed by the same letter are not significantly different (p = 0.05).

hat weighed 2 and 20 mg (i.e., about the range of veights used in the study) specific needle areas were bout 200 and 110 cm^2/g needle weight (equations 4a nd 4b). For tamarack needles weighing 0.8 and 8.0 mg he specific needle areas were 264 and 126 cm^2/g needle ry weight (equations 7a and 7b).

DISCUSSION

In both species the curvilinearity in relations between eedle length and surface area or dry weight and etween needle weight and surface area was eliminated y logarithmic transformation. The curvilinearity among eedle measurements and its linearization by applying he allometric model was discussed by Madgwick (1964) n his studies on red pine. An allometric model was also sed by Harms (1971) for estimating fascicle needle area f loblolly pine; for the same species Kinerson *et al.* 1974) and Higginbotham (1971) used simple linear egressions in relation between foliage weight or needle ascicle length and the corresponding surface area. owever, Kinerson *et al.* (1974) and Higginbotham 1971) had to develop separate equations for the upper, iddle, and lower thirds of the crown to account for ifferences in needle morphology which is apparently ot needed when using the allometric model.

In both species the smallest needles were in the lower hird and the largest in the upper third of the crown. As result, the specific leaf area, expressed in cm^2/g of eedles decreased from the lower to the upper third of he crown. The relation of specific needle (or foliage) rea to position in the crown was also reported in other tudies. Using Kinerson's *et al.* (1974) data for loblolly ine, we calculated specific foliage areas of 122, 99, and 2 cm^2/g for the lower, middle, and upper thirds of the rown, respectively. Assuming that the distribution of eedles in crowns of red pine studied by Madgwick 1964) was similar to the distribution found in our tudies, the specific needle area of the smallest fascicles 18.9 mg) of red pine would be about twice that of the argest fascicles (119.5 mg).

More information is available on the specific leaf area istribution of broadleaved species. Pieters (1974) re- orted that sun leaves of *Quercus borealis* and *Acer seudoplatanus* were about twice as thick as shade eaves. In *Fagus sylvatica* (Vanseveren 1973) the specific eaf area of fully developed leaves ranged from 104 to 84 cm^2/g for leaves collected from the upper and lower hirds of the crown. The average specific leaf areas of quaking aspen leaves collected from the upper and lower thirds of the crown of a codominant tree were 120 and 147 cm^2/g, respectively (Zavitkovski 1971). Our unpublished studies of dense plantations of *Populus* 'Tristis #1' indicate that the average specific leaf area of leaves collected from the upper third of crowns is about 102 cm^2/g whereas from the lower third it is about 211 cm^2/g. It must be noted that in calculations of specific leaf area only one side of the broadleaved leaves, but the entire surface of needles is considered.

The differences in needle morphology resulting from the position in the crown were more pronounced in samples collected from dense plantations in which the lowermost needles were growing in dense shade and the uppermost in full sunlight. This seems to be consistent with studies of Pieters (1974) who concluded that leaf thickness increases with light and decreases with temperature. The same principle applied to loblolly pine in which needles developing in the shaded part of the crown were thinner and had a smaller area than needles exposed to full light (McLaughlin and Madgwick 1968).

The difference in the mean values between the 1974 and 1975 needles of jack pine trees, and, as a consequence, the absence of a pronounced relation in the 1974 needle length, surface area, and dry weight with position in the crown, could have resulted from a premature death and fall of the short needles that predominate in the lower third of the crown. Late summer 1975 sampling of the 1974 needles would then be biased in favor of the larger needles. This conclusion is supported by our unpublished studies on the periodicity of leaf fall in plantations of *Populus* 'Tristis #1' which revealed that the smallest leaves senesce and fall first.

We found no relation between tree d.b.h. and needle length, which was reported for ponderosa pine by Cable (1958), probably because of the relatively narrow d.b.h. range of our sample trees that grow in even-aged plantations.

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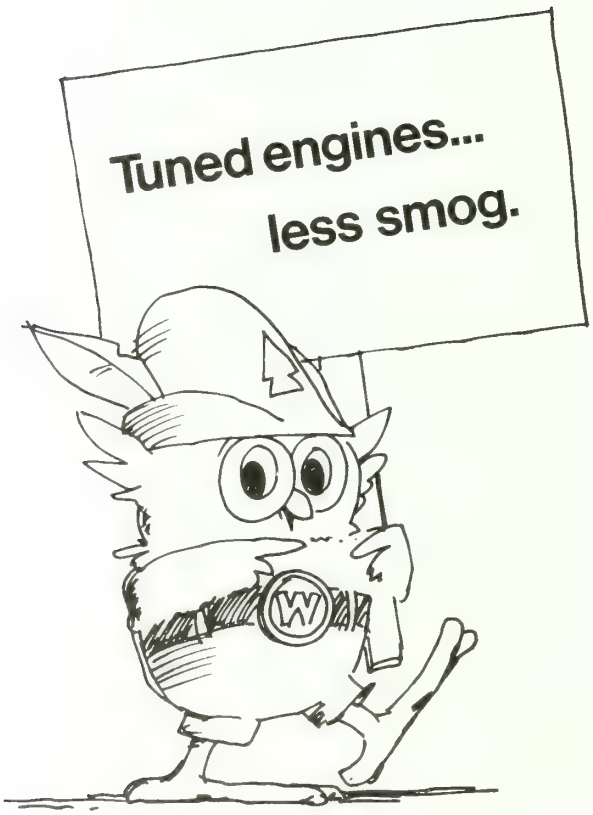
Tuned engines...
less smog.

FOREST SERVICE
ARCH PAPER NC-154

WEATHERING EFFECTS on fuel MOISTURE STICKS: corrections and recommendations.

DONALD A. HAINES AND JOHN S. FROST

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1978

EATHERING EFFECTS ON FUEL MOISTURE STICKS: CORRECTIONS AND RECOMMENDATIONS

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APPLICATION

The National Fire-Danger Rating System FDRS) (Deeming *et al.* 1977) and other systems quire measurement of fuel moisture to evaluate otential fire behavior and fire danger. Currently, -inch diameter, 100 gram, ponderosa pine owels are used in the NFDRS to measure fuel oisture in the 10-hour timelag class. We found at the magnitude of moisture content error creases as these sticks weather.

HOW TO CORRECT MOISTURE CONTENT OBSERVATIONS

You can correct moisture content readings of -inch, 100 gram, ponderosa pine dowels posed to the atmosphere at the usual 10-inch eight above the ground as follows: (1) Weigh the ick and observe its moisture content; (2) Find e observed moisture content along the hori- ntal axis of figure 1: (3) Extend a line vertically om this axis to the line on the graph that rresponds to the number of months that the ick has been exposed (fig. 1); and (4) Extend a ne horizontally to the vertical axis and read the rrected value.

RECOMMENDATIONS FOR USE OF FUEL MOISTURE STICKS IN NFDRS

Uncorrected readings of moisture content in fuel sticks that have weathered for a month or more can affect NFDRS final values, especially in the Energy Release Component (ERC) and the Burning Index (BI). In order to obtain more accurate results we recommend the following: (1) If you primarily require a grass or timber fuel model in your fire protection area, use a single stick throughout a fire season, unless the stick collects excessive dust, dirt, or other atmospheric pollutants. Observation corrections can be made by following the procedures listed above. (2) If you primarily require a brush or slash fuel model in your protection area, replace the stick once or twice during the fire season if wet or very humid conditions cause rapid weathering, or if the stick collects excessive dust, dirt, or other atmospheric pollutants. In all cases make corrections before observations are entered into the NFDRS. (3) Regardless of fuel model, replace sticks if they have checks, cracks, or damage by rodents or fungi. Also, discard all fuel moisture sticks after one season's use.

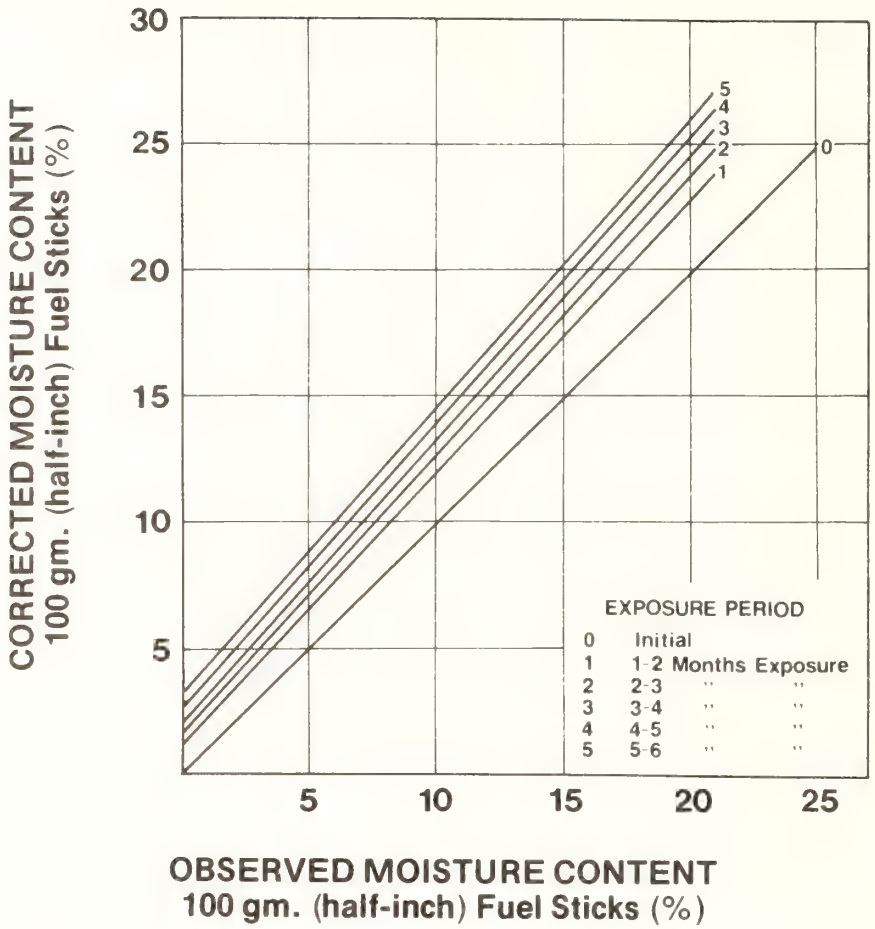

Figure 1.—*Chart for correcting the observed moisture content of fuel sticks [located 10 inches above the ground] according to the exposure period. To use, find stick weight reading at observation on the horizontal axis; extend a line vertically to the curve corresponding to the exposure period of the stick; extend a line horizontally to the vertical axis and read the corrected value.*

DOCUMENTATION

n the National Fire-Danger Rating System DRS) dead fuels are delineated by their sture timelag, as defined by Deeming *et al.* 77), and grouped by 1-, 10-, 100-, and 00-hour classes. Values of the 10-hour class, ally determined by measurement of 100-gram inch) fuel moisture sticks (Gisborne 1933), er all components of the System but are ecially important in computing the Energy ease Component (ERC) and Burning Index . However, exposed fuel sticks used to ermine fuel moisture are subject to processes t could induce measurement errors. These ors include dry-weight changes, timelag chang- and perhaps changes in the characteristic tion between equilibrium moisture content temperature-relative humidity.

Veight loss induced by weathering of basswood s used as 1-hour fuel moisture analogues in ier Danger Systems received much attention n both operational and research personnel. As result, suppliers included a time-weight rection card with each basswood analogue lson 1965). No such elaborate precautions e devised for the presently used ½-inch derosa pine dowels. Thus, it became neces- y to determine the rate of change of these oden fuel moisture analogues in relation to r environment and to develop weathering rections for them.

METHODS

From May 1 to November 1, 1975, standard -gram wooden dowel sets were exposed over a natural litter fuel bed located in East Lansing, Michigan. At the beginning of this period four sets of sticks were exposed, two in direct contact with the litter and two on wire racks at the standard 10-inch height. Four additional sets, two on the racks and two on the ground, were sequentially exposed every 4 weeks. All sticks were of similar manufacture. Weights of all sticks and routine, supplementary weather data were taken daily at 1300 local standard time (1.s.t.). At the end of the 6-month period all sticks were ovendried and their weight loss recorded. Although there was discoloration of the wood in relation to the length of exposure, no checking, cracking, or exceptional fungal activity was evident.

ANALYSIS AND DISCUSSION

Weather

Principal weather factors affecting fuel-moisture during the exposure season are listed in table 1. Rain amounts were below average each month except for an extremely wet August. On the other hand, days with rain were near average over the course of the season. More importantly, almost every night had rain, dew, or both. The dew observations aren't complete for May and June, but available records indicate that these 2 months were equally wet. In a study of weathering effects on accuracy of fuel-moisture indicator sticks in the Pacific Northwest, Morris (1959) concluded that heavy dew, regardless of rain, caused the greatest weathering observed west of the Cascades. Therefore, the frequent dew-rain nights in the East Lansing area would also tend to increase the

Table 1.—*Summarized weather records, May to October 1975 for East Lansing, Michigan*

	Mean temperature		Precipitation amount		Days > 0.01 inches precipitation		1975 Dew &/or rain nights[1]	Possible sunshine		1975 Relative humidity departure from average (hours)			
	30 years	1975	Mean	1975	Mean	1975		Mean	1975	0100	0700	1300	1900
	Degrees F		*Inches*		*Number*			*Percent*					
May	56.8	61.3	3.51	2.81	11	12	--	62	64	+13	+12	+ 3	+ 4
June	67.1	68.4	3.80	2.38	11	10	—	65	53	+ 8	+ 9	+ 8	+ 8
July	70.9	70.6	2.88	1.92	9	9	29	70	67	+ 6	+ 7	0	0
Aug	69.5	69.6	3.27	8.23	10	14	28	66	46	+ 5	+ 6	+10	+10
Sept	61.7	56.2	2.48	2.05	10	7	29	58	49	- 5	- 6	- 3	- 2
Oct	51.6	52.2	2.38	0.93	8	6	25	54	61	-11	- 9	-12	-11

[1]Includes all morning observations with dew of any amount on the Durderani Dew Gage.

weathering effect relative to many other regions of the country. Another important factor in the present study is the high humidity observed during the first 4 months of record. It may have caused a more intense weathering season.

References

Daily observations of fuel moisture were compared to two "references", one for ground sticks and one for elevated sticks. Reference sticks were defined as "the most recently exposed fuel moisture sticks", since these were assumed to give the most accurate and true value of fuel moisture conditions. All moisture values of dowels that had been exposed longer were taken as a departure from either the ground or the elevated reference. As additional sets of sticks were exposed every 4 weeks, they automatically became the new references. Because of the method of analysis (using references), departures could not be computed until after a second set of sticks was installed.

Ground-Exposed Fuel Moisture Sticks

Because weathering effects vary with current stick moisture content, daily readings of moisture content in the reference sticks were divided into six convenient groups covering 171 days that weather allowed observations as shown below:

Reference sticks Moisture content	*Frequency of occurrence*	
	Ground-exposed	*Elevated*
	-----(percent)-----	
6 to 7	13	
8 to 10	30	17
11 to 13	20	44
14 to 16	14	16
17 to 24	12	14
25+	11	9
	100	100

No ground-stick fuel moistures below 6 percent were observed for the references on any day during the period of record. Consequently we interpolated through the 0 to 6 percent moisture range during analysis. Because sticks weigh 100-grams, all weights are directly convertible to percent moisture.

Interestingly, the ovendry weights of tl ground sticks (fig. 2) showed nearly the san weight loss at the end of the season as tl elevated sticks (fig.3). However, at various tin intervals over the exposure period there we distinct differences. Ground sticks displayed mo erratic changes.

Through the first 2 to 3 months of exposure th ground fuel moisture groups were separated l weight loss. Differentiation and pattern identi of the ground groups were not distinct in tl following months of exposure except for the 17 24 percent fuel moisture group. This wou indicate that if ground-exposed sticks are used the future, they should be replaced at 2- 3-month intervals.

Elevated Fuel Moisture Sticks

These stick weights, also recorded at the dai observation, showed a lesser range of moistu contents than the ground-exposed sticks.

Weight loss, when sticks were ovendried, vari from almost 1 gram for sticks exposed for 1 mon to over 3 grams for those exposed during tl entire 6 months (fig. 3). Graphing of other fu moisture groups showed a well delineated fami of curves with the 8 to 10 percent fuel moistu group having the least departure from referen and the 17 to 24 percent group having the mos Unlike the ground stick fuel moisture group differentiation and pattern identity were not los

IMPLICATIONS

During ambient exposure, either at the stan ard 10-inch height or in contact with duff, wood fuel moisture sticks lose weight. This loss probably due to erosion of water solubles, fung activity, and perhaps sublimation of woo materials. Data show that the resultant err increases with the length of stick exposure a higher average moisture content. This error consistently negative; i.e., old sticks indicate lower 10-hour moisture content than new stick During analysis of these data we emphasized tin change in stick moisture content. A discussion this change as applied to select NFDRS fu models is given in this section.

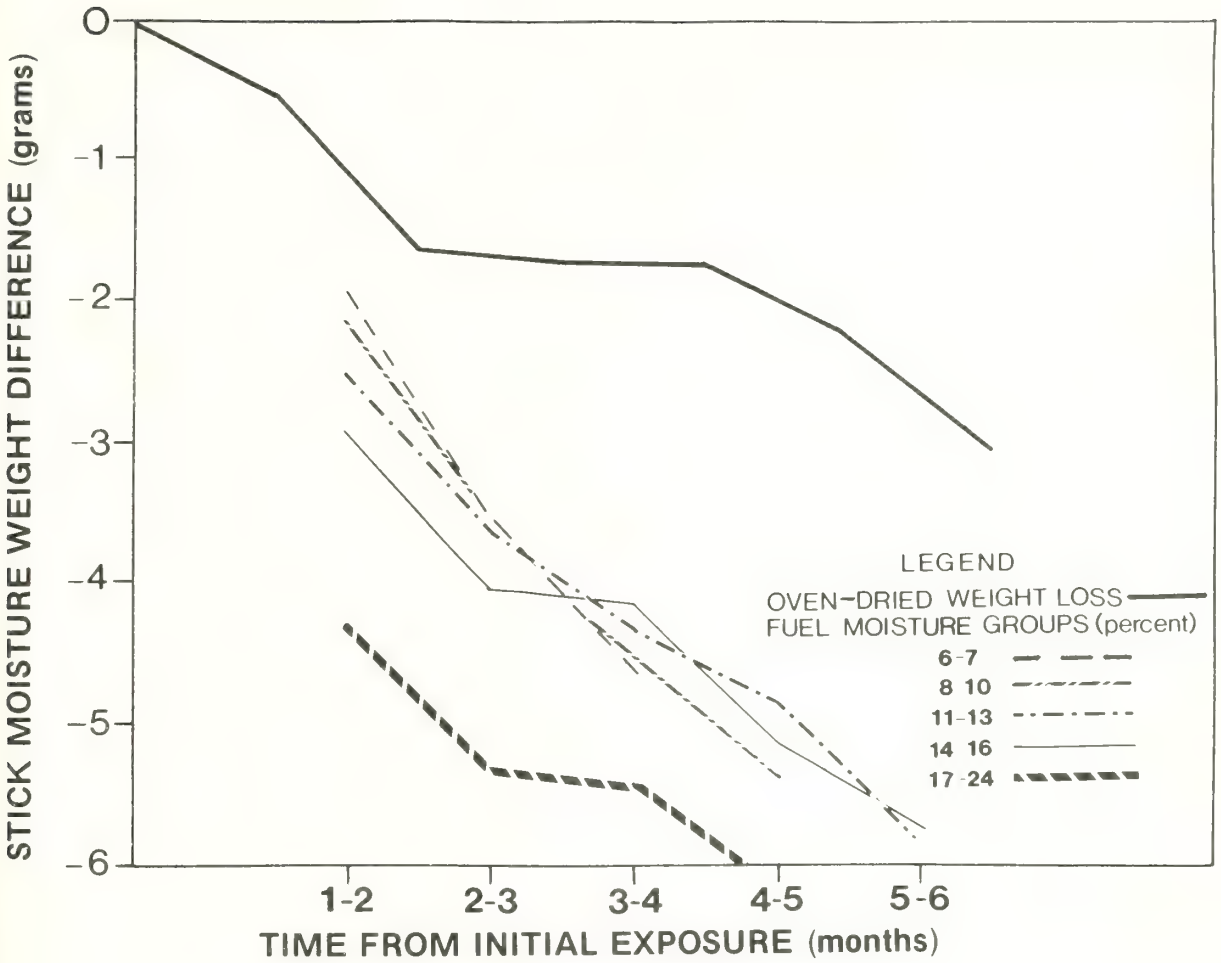

Figure 2.—*Ground stick weight loss with exposure time. Weight reading differences are relative to weight readings of the most recently exposed sticks [the reference]. Ovendried weight was determined by gravimetric analysis, 105 C for 24 hours.*

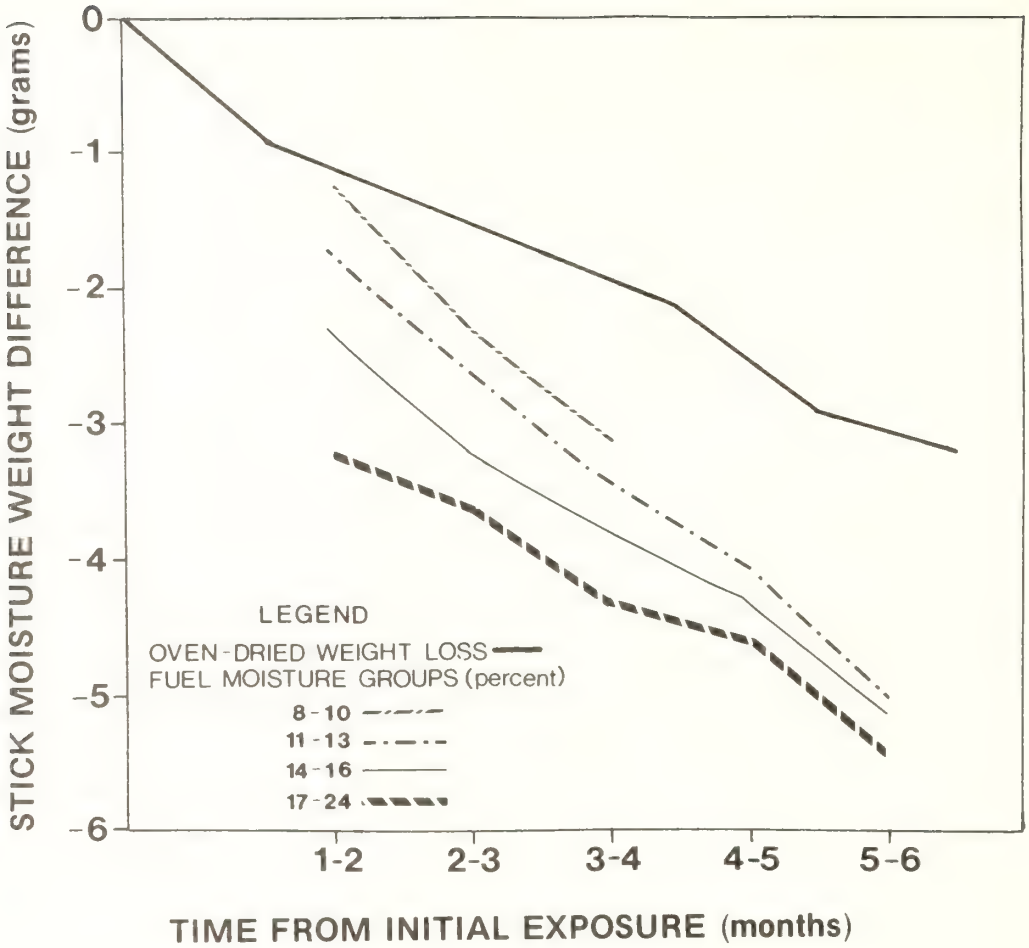

Figure 3.—*Elevated stick weight loss with exposure time. Weight reading differences are relative to weight readings of the latest exposed sticks [the reference].*

Previous studies of stick weight change with time considered only ovendry weight loss (Morris 1959). Therefore, it is difficult to estimate the differences from our moisture group values that one might expect in other regions of the country. Our ovendry weights showed an average loss of 0.53 gram per month over the season. Morris found the following average monthly losses in areas of the Northwest: Coastal strip of Oregon, 0.67 gram; west slope of the Cascades, 0.45 gram; east slope of the Cascades, 0.35 gram; Ochoco Mountain and northeast Oregon, 0.27 gram.

As a first approximation we believe our data
fairly representative for the country. Treating
elevated stick departures from reference as lin
trends produce a graph of observed ver
corrected weights (fig.1). In areas with m
climates, such as the coastal mountains of
Pacific Northwest, the departures between
served and actual should be somewhat grea
than shown. In areas with dry climates, such
the Southwest, they will be somewhat less.

Because moisture values of elevated fuel sti

e an integral part of the NFDRS, the use of ıcorrected readins from aged sticks could affect e final values of the System, especially the ERC ıd BI. To show the magnitude of errors in ERC ıd BI caused by different weathering times of icks, representative values were assigned to four el models (tables 2 and 3).

able 2.—*Effect of exposure of the 100-gm fuel moisture sticks on the Energy Release Component values of the NFDRS, using four fuel models*[1]

Fuel model	Time of exposure (months)					
	0	1-2	2-3	3-4	4-5	5-6
B	25	27	30	33	35	39
G	42	42	43	43	44	44
H	21	22	22	23	23	24
J	144	152	156	160	165	174

[1]For this illustration, the following representative values were assigned: fine fuel moisture, 6 percent; reference 10-hour class, 9 percent; 100-hour class, 12 percent; 1000-hour class, 15 percent.

able 3.—*Effect of exposure of the 100-gm fuel moisture sticks on the Burning Index values of the NFDRS, using four fuel models*[1]

Fuel model	Time of exposure (months)					
	0	1-2	2-3	3-4	4-5	5-6
B	31	32	34	35	37	38
G	44	44	44	45	45	45
H	17	18	18	18	18	18
J	149	159	161	163	166	177

[1]The constants assigned are the same as those in table 2, plus: wind speed, 20 mph; slope, class I; herbaceous vegetation, zero percent green.

The magnitude, and therefore the importance, of weathering error depends on the type of fuel model used because the ratio of the 10-hour class fuel loading to total loading varies with model (Deeming *et al.* 1977). Timber types are not heavily weighted toward 10-hour timelag fuels. For example, in model G the ratio of 10-hour class fuel loading to total loading is 9 percent, while the loading ratio of models I,J,K, (slash) are 26 or 27 percent.

Stick weathering caused relatively small changes with time in the ERC and BI for timber fuels (models G and H): there is a difference of 2 or 3 units in the ERC and 1 unit in the BI over the fire season (tables 2 and 3). On the other hand, there is an ERC change of 14 and a BI change of 7 for brush-type fuel model B and corresponding changes of 30 and 28 units for slash-type fuel model J. These data lead to the recommendations given in the Application section.

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OXFORD: 431.5:431.2. KEY WORDS: fire danger, fire-weather observations, fuels, dew.

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Economic VALUES for growth and grade changes of SUGAR MAPLE in the Lake States

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ECONOMIC VALUES FOR GROWTH AND GRADE CHANGES OF SUGAR MAPLE IN THE LAKE STATES

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Sugar maple is the major species in volume and ue in the northern forests of the Lake States. Its nomic importance is largely attributable to the mand for the quality lumber that is manufac- ed into specialized products. As a result of past mand, nearly 90 percent of the sugar maple ea now consists of second-growth stands. thin these stands the quality and potential ue of sugar maple are extremely variable and ist be developed through silvicultural manage- nt.

Initial management in the sugar maple types olves the removal of the cull, poor-risk and v-quality trees. Subsequently, however, the nagement must consider both silviculture and nomics in deciding which trees to grow and w large to grow them. At this stage of forest velopment these two disciplines are so inextric- ly involved as to influence the final outcome of e management venture. Silviculturally we can rease diameter growth, extend merchantable ight and select trees of good form and bole as p trees. With a clear understanding as to how provements in these physical characteristics rease tree value, we can then properly evaluate r silvicultural recommendations and put tree- wing on a sound-financial basis.

Value has been a neglected dimension in estry, often considered only at harvest time. In s publication, we will explain a method of culating tree value. Then we will show how to e this value to calculate the financial maturity of tree—that point in time at which the rate of lue-increase falls below the owner's desired e of return.

The financial maturity concept is especially useful in hardwood management. It expresses the physical variations in trees and their projected changes in economic terms.

METHODS

The determination of tree value is more complex than merely multiplying the board foot volume of a tree by the price per thousand board feet. Trees of different size and quality produce various amounts of the different grades of lumber and each grade commands a different price in the market. In our procedure we account for these differences and the resulting change in tree value. This procedure is explained in a flow chart diagram (fig. 1) and a step-by-step narration in the following text.

Tree values are determined from the amount and quality of 4/4 lumber that can be sawed from the tree. In our calculations we used the lumber grade recovery data for maple from the Forest Products Laboratory (Vaughn *et al.* 1966). Lumber price relatives were developed from prices reported in the Hardwood Market Report (Lemsky 1962-1966). Prices were averaged over the 5-year period and the price ratios for the price of No. 1 Common lumber were determined from calculation of the log quality index. (A more complete documentation of the log quality index calculation can be found in Mendel and Smith (1970)). It is suffice to know that the log quality index is a single number that, when multiplied by the price

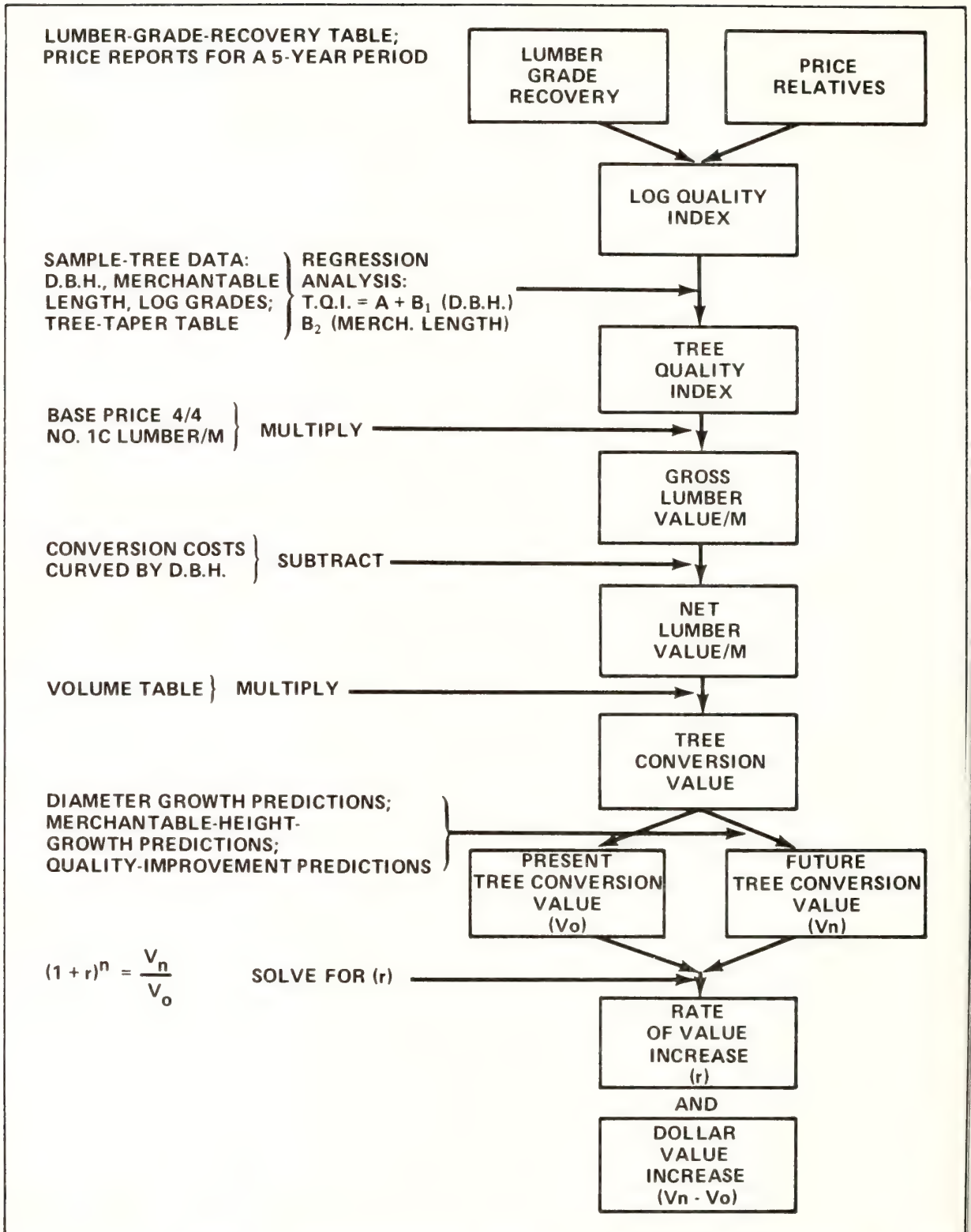

Figure 1.—*Calculation of rate of value increase.*

4/4 No. 1C lumber and the volume, will express e value of the 4/4 lumber that can be sawed om the log:

Lumber value = (Q.I.) x (Price of 4/4 No. 1C) x lume of log
1,000

Our next step was to translate log quality index tree quality index, because we are interested in ees rather than logs. To do this it was necessary establish the relation between the grades of the tt-log and the upper merchantable logs for rious diameter sugar maple trees. We used mple tree data from the Argonne and Upper eninsula Experimental Forests in Wisconsin and ichigan for this. By means of regression analysis e established this relation which can be pressed as:

Tree Quality Index = (percent of the tree volume in 1st log x log $Q.I._{1st\ log}$) plus (percent of volume in 2nd log x log $Q.I._{2nd\ log}$) plus (percent of volume in nth $_{log}$ x log $Q.I._{nth\ log}$)

hen we calculated gross lumber value per thou- nd board feet. In our calculations, we used a rice of $165 for 4/4 No. 1C sugar maple lumber emsky 1962-1966). The gross lumber value was etermined by multiplying the tree quality index y the appropriate price.

To determine net lumber value it is necessary to educt the direct costs involved in converting the anding tree into 4/4-inch lumber. Such costs volve all the labor and material used in felling, ucking, transporting the logs to the mill, and awing the logs into lumber. In this study, three vels of costs were used: $60, $70, and $80 per ousand board feet for a 16-inch d.b.h. tree.

Tree conversion value was calculated by ultiplying the net lumber value by the volume of mber in the tree. The 1/4-inch International olume table was used to determine the volumes.

We have now approached an important juncture the schematic flow of calculations. First, it is nportant to note that tree conversion values are resent conversion values, i.e., present tree alue. Nothing need be done to convert from one the other. It was necessary to make this change nomenclature because at this point we will egin considering conversion values 10 years in the future and certain assumptions concerning diameter growth, merchantable-height growth, and quality improvement must be made. The 10-year period was selected because it is the recommended cutting cycle for most silvicultural systems. The assumptions were based on research data from experimental forests in Wisconsin and Michigan.

Diameter.—Three different 10-year diameter growth rates were used (1.4, 1.8, and 2.2 inches) to account for the variable site conditions on which sugar maple in the Lake States can be found.

Height.—Research indicates that a 1/2-log height growth is possible in 10 years on trees of good form.

Grade.—In growing trees, quality improvement is as important as diameter and height growth. For grade improvement, scanty research data indicate that a 1-grade improvement is possible within a 10-year period and thus we considered the occurrence of such an event.

We regarded the probability of height or grade improvement to be rather remote once the tree was 25 inches d.b.h. and did not consider such improvements in our calculations.

With these assumptions based on research we were able to project the dimensions of sugar maple trees 10 years into the future and by referring to our table of tree conversion values were able to determine future conversion value of the tree. We then calculated the rate of value increase of the tree during the 10-year period using the compound interest formula:

$$(1 + r)^n = \frac{V_n}{V_o}$$

where: r is the rate of value increase

n is the time period (10 years)

V_n is the future conversion value

V_o is the present conversion value.

This value determines the point of financial maturity of the tree. When the rate falls below the rate of return desired by the owner, the tree is financially mature.

One simple calculation completes the procedure. To set the tree value increase over the 10-year period, we simply subtracted the present conversion value from the future conversion value.

These are the calculations involved in a single example of financial maturity. In our work, with the aid of a computer, we made several thousand such calculations of tree diameters 14 to 30 inches d.b.h., merchantable heights up to 3-1/2 logs, and all 3 grades of logs.

Because lumber prices and conversion costs vary, we could not hope to duplicate current prices. Instead we used a base lumber price of $165 for 4/4 No. 1C lumber and a $70 conversion cost. Then, to illustrate the effect of changing lumber prices and conversion costs, we made a series of computations for assumed combinations of prices and costs as follows:

We termed this "the basic situation"

	Present	(10 years hence)
Price 4/4 No. 1C	165	$175/M
Conversion Cost	70	70/M

Other lumber-price, conversion-cost combinations were:

Price 4/4 No. 1C	165	165
Conversion Cost	80	80
Price 4/4 No. 1C	165	165
Conversion Cost	70	70
Price 4/4 No. 1C	165	165
Conversion Cost	60	60
Price 4/4 No. 1C	165	165
Conversion Cost	70	60
Price 4/4 No. 1C	165	175
Conversion Cost	70	60

Prices of lumber are subject to the law of supply and demand. Over-abundance of a species at any one time can drive the price down. Costs can also be reduced by innovation and use of labor-saving machines. So our combinations are not unrealistic.

RESULTS

Present Dollar Value

The dollar value of individual trees follows t normal pattern: value increases with tree dian ter and is greater on trees with more mercha able height and on those with the highest butt l grade (table 1). The value of a 2-log, grade 2 tr for example, is $2.73 for 14-inch trees and $53. for 30-inch trees.

Within the same diameter-grade class, tre with greater merchantable heights have high net values. A 16-inch, 2-log, butt log grade 2 tr has a value of $5.14 in contrast to a 1-1/2-log tr which has a value of $4.40.

Dollar Value Increases for Grow and Grade Charges

In order to obtain the greatest dollar-earn capacity, choices must be made after the f thinning among trees with different potentials development. In conjunction with silvicultu knowledge of the species, the three major fact that can be evaluated are the expected change diameter growth as a result of treatment a altering of growing space, the projected incre in merchantable height, and the probability of increase in grade due to clearing of bole defe and size. The amount of value increase can determined for individual trees, for each facto a combination of the three major factors (table

Diameter growth will normally occur on residual trees either at a constant rate typica the previous management level or at an increa rate following treatment that usually can estimated on the basis of three broad gro classes. The value contributed by increase in is directly related to the rate of growth. Ov 10-year period, for example, the increase in va for a 16-inch, 2-log, butt log grade 2 tree wit present value of $5.14 would be $3.54 if it grew inches in diameter, $4.36 with a growth inches, and $5.22 for a growth of 2.2 incl assuming there was no increase in grade.

Table 1.—*Expected 10-year value increases in sugar maple for given increases in diameter, height, and grade*
(In dollars)

Present				Diameter growth only			Diameter growth + 1/2 log ht. inc.			Diameter growth + 1 grade increase			Diameter growth + 1/2 log ht. inc. and 1 grade increase		
D.b.h. (inches)	Merch.-height (logs)	Butt log grade	Value (dollars)	(D.b.h. growth-inches) 1.4	1.8	2.2	(D.b.h. growth-inches) 1.4	1.8	2.2	(D.b.h. growth-inches) 1.4	1.8	2.2	(D.b.h. growth-inches) 1.4	1.8	2.2
14	1	1	-				-	-	-	-	-	-	-	-	-
		2	1.86	1.61	1.88	2.26	2.62	3.11	3.63	3.99	4.47	4.97	6.03	6.69	7.37
		3	0.29	0.91	1.11	1.32	1.50	1.78	2.09	3.08	3.45	3.83	4.18	4.68	5.20
14	1 1/2	1	-	-	-					-	-	-	-	-	-
		2	2.41	2.07	2.57	3.09	2.81	3.42	4.06	5.48	6.14	6.83	6.95	7.78	8.63
		3	0.50	1.29	1.57	1.88	1.84	2.21	2.60	3.97	4.47	4.99	4.72	5.32	5.97
14	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-
		2	2.73	2.49	3.10	3.74	3.32	4.01	4.73	6.63	7.45	8.31	8.33	9.25	10.20
		3	0.73	1.62	1.98	2.37	2.31	2.75	3.21	4.49	5.10	5.74	5.32	6.01	6.73
16	1	1	5.80	2.70	3.42	4.08		-	-	-	-	-	-	-	-
		2	3.31	2.12	2.67	3.21	-	-		5.19	5.91	6.57	-	-	-
		3	1.04	1.32	1.63	1.94	-	-		4.39	4.95	5.48	-	-	-
16	1 1	1	7.84	3.74	4.59	5.46	6.07	7.11	8.19	-	-	-	-	-	-
		2	4.40	2.91	3.59	4.29	4.29	5.11	5.97	7.17	8.02	8.90	9.51	10.55	11.63
		3	1.58	1.88	2.28	2.71	2.89	3.40	3.94	5.73	6.41	7.11	7.11	7.93	8.79
16	2	1	9.34	4.57	5.61	6.68	6.93	8.17	9.42	-	-	-	-	-	-
		2	5.14	3.54	4.36	5.22	4.88	5.85	6.86	8.77	9.81	10.88	11.12	12.35	13.61
		3	2.10	2.37	2.88	3.42	3.50	4.13	4.80	6.59	7.41	8.27	7.93	8.90	9.91
16	2 1/2	1	10.98	5.29	6.51	7.78	7.72	9.13	10.59	-	-	-	-	-	-
		2	5.93	4.10	5.07	6.08	5.45	6.56	7.72	10.34	11.57	12.83	12.77	14.18	15.64
		3	2.73	2.87	3.50	4.16	4.17	4.92	5.72	7.29	8.26	9.27	8.64	9.75	10.91
18	1	1	8.54	3.60	4.43	5.27	-	-	-	-	-	-	-	-	-
		2	5.43	2.93	3.61	4.32	-	-	-	6.71	7.54	8.38	-	-	-
		3	2.20	1.86	2.27	2.70	-	-	-	-	-	-	-	-	-
18	1 1/2	1	11.49	4.84	5.90	6.99	-	-	-	-	-	-	-	-	-
		2	7.23	3.93	4.81	5.73	-	-	-	9.10	10.16	11.26	-	-	-
		3	3.21	2.59	3.15	3.72	-	-	-	-	-	-	-	-	-
18	2	1	13.82	5.86	7.14	8.54	9.36	11.02	12.65	-	-	-	-	-	-
		2	8.58	4.75	5.81	6.98	6.99	8.35	9.70	11.09	12.37	13.77	14.59	16.26	17.89
		3	4.17	3.25	3.93	4.69	5.09	5.99	6.90	-	-	-	-	-	-
18	2 1/2	1	16.15	7.03	8.69	10.32	10.20	11.92	13.75	-	-	-	-	-	-
		2	9.90	5.67	7.03	8.38	7.64	9.07	10.60	13.27	14.94	16.57	16.45	18.16	20.00
		3	5.25	4.00	4.90	5.81	5.89	6.87	7.94	-	-	-	-	-	-

(Table 1 continued on next page)

(Table 1 continued)

Present				Diameter growth only			Diameter growth + 1/2 log ht. inc.			Diameter growth + 1 grade increase			Diameter growth + 1/2 log ht. inc. and 1 grade increase		
D.b.h. (inches)	Merch. height (logs)	Butt log grade	Value (dollars)	(D.b.h. growth-inches)			(D.b.h. growth-inches)			(D.b.h. growth-inches)			(D.b.h. growth-inches)		
				1.4	1.8	2.2	1.4	1.8	2.2	1.4	1.8	2.2	1.4	1.8	2.2
18	3	1	18.54	7.82	9.53	11.37	10.53	12.59	14.63	-	-	-	-	-	-
		2	11.21	6.33	7.76	9.29	7.96	9.64	11.34	15.14	16.85	18.69	17.85	19.91	21.96
		3	6.49	4.65	5.64	6.70	6.51	7.71	8.93	-	-	-	-	-	-
20	1	1	12.12	4.46	5.59	6.64	-	-	-	-	-	-	-	-	-
		2	8.34	3.76	4.71	5.63	-	-	-	8.24	9.37	10.42	-	-	-
		3	3.88	2.45	3.04	3.61	-	-	-	-	-	-	-	-	-
20	1 1/2	1	16.12	6.16	7.38	8.81	-	-	-	-	-	-	-	-	-
		2	11.01	5.16	6.23	7.46	-	-	-	11.28	12.50	13.93	-	-	-
		3	5.50	3.46	4.15	4.94	-	-	-	-	-	-	-	-	-
20	2	1	19.50	7.56	9.30	11.00	12.21	14.29	16.42	-	-	-	-	-	-
		2	13.20	6.32	7.80	9.27	9.53	11.30	13.12	13.86	15.60	17.29	18.51	20.58	22.71
		3	7.07	4.36	5.34	6.31	7.00	8.20	9.44	-	-	-	-	-	-
20	2 1/2	1	23.07	8.64	10.71	12.84	12.74	14.96	17.33	-	-	-	-	-	-
		2	15.49	7.25	9.01	10.84	10.03	11.93	13.96	16.22	18.30	20.43	20.33	22.55	24.92
		3	8.89	5.19	6.38	7.62	7.80	9.14	10.56	-	-	-	-	-	-
20	3	1	26.04	9.77	11.99	14.36	13.77	16.22	18.73	-	-	-	-	-	-
		2	17.32	8.20	10.10	12.13	10.85	12.95	15.13	18.50	20.72	23.09	22.49	24.94	27.45
		3	10.64	6.05	7.38	8.81	8.83	10.35	11.92	-	-	-	-	-	-
20	3 1/2	1	28.85	10.96	13.41	15.92	13.94	16.60	19.41	-	-	-	-	-	-
		2	19.00	9.17	11.27	13.44	11.07	13.34	15.76	20.81	23.26	25.77	23.79	26.45	29.26
		3	12.51	6.97	8.49	10.06	9.46	11.15	12.95	-	-	-	-	-	-
22	1	1	16.56	5.55	6.73	7.80	-	-	-	-	-	-	-	-	-
		2	12.10	4.78	5.81	6.76	-	-	-	10.01	11.19	12.26	-	-	-
		3	6.16	3.14	3.76	4.34	-	-	-	-	-	-	-	-	-
22	1 1/2	1	21.93	7.49	8.94	10.49	-	-	-	-	-	-	-	-	-
		2	15.94	6.44	7.72	9.08	-	-	-	13.48	14.94	16.49	-	-	-
		3	8.59	4.34	5.14	5.98	-	-	-	-	-	-	-	-	-
22	2	1	26.92	9.06	11.07	13.08	-	-	-	-	-	-	-	-	-
		2	19.45	7.79	9.54	11.29	-	-	-	16.53	18.54	20.55	-	-	-
		3	11.10	5.42	6.53	7.65	-	-	-	-	-	-	-	-	-
22	2 1/2	1	31.53	10.65	12.53	14.69	16.42	18.92	21.43	-	-	-	-	-	-
		2	22.64	9.16	10.84	12.74	13.34	15.53	17.73	19.54	21.42	23.58	25.31	27.81	30.32
		3	13.68	6.55	7.67	8.91	10.32	11.82	13.30	-	-	-	-	-	-
22	3	1	35.46	12.49	14.99	17.50	17.38	20.29	23.21	-	-	-	-	-	-
		2	25.30	10.68	12.87	15.07	14.16	16.69	19.23	22.65	22.15	27.66	27.54	30.45	33.37
		3	16.18	7.83	9.32	10.80	11.43	13.21	14.98	-	-	-	-	-	-
22	3 1/2	1	39.36	13.48	16.40	19.31	18.15	21.46	24.78	-	-	-	-	-	-
		2	27.90	11.57	14.10	16.64	14.84	17.69	20.56	24.95	27.86	30.78	29.61	32.93	36.24
		3	18.87	8.74	10.52	12.28	12.49	14.55	16.62	-	-	-	-	-	-

(Table 1 continued on next page)

(Table 1 continued)

Present				Diameter growth only (D.b.h. growth-inches)			Diameter growth + 1/2 log ht. inc. (D.b.h. growth-inches)			Diameter growth + 1 grade increase (D.b.h. growth-inches)			Diameter growth + 1/2 log ht. inc. and 1 grade increase (D.b.h. growth-inches)		
D.b.h. (inches)	Merch.-height (logs)	Butt log grade	Value (dollars)	1.4	1.8	2.2	1.4	1.8	2.2	1.4	1.8	2.2	1.4	1.8	2.2
24	1	1	21.75	6.14	7.32	8.61	-	-	-	-	-	-	-	-	-
		2	16.62	5.36	6.42	7.56	-	-	-	11.27	12.44	13.73	-	-	-
		3	8.91	3.41	4.02	4.68	-	-	-	-	-	-	-	-	-
24	1 1/2	1	28.88	8.20	9.86	11.63	-	-	-	-	-	-	-	-	-
		2	21.98	7.16	8.63	10.20	-	-	-	15.10	16.76	18.53	-	-	-
		3	12.38	4.69	5.56	6.49	-	-	-	-	-	-	-	-	-
24	2	1	35.56	10.49	12.52	14.55	-	-	-	-	-	-	-	-	-
		2	26.95	9.12	10.92	12.73	-	-	-	19.10	21.12	23.16	-	-	-
		3	15.94	6.12	7.22	8.33	-	-	-	-	-	-	-	-	-
24	2 1/2	1	41.01	12.39	14.65	17.13	19.45	21.95	24.66	-	-	-	-	-	-
		2	30.94	10.73	12.76	14.95	16.08	18.32	20.73	22.46	24.72	27.20	29.52	32.02	34.73
		3	19.23	7.41	8.68	10.06	12.15	13.61	15.17	-	-	-	-	-	-
24	3	1	47.09	13.37	15.87	18.58	20.34	23.27	26.20	-	-	-	-	-	-
		2	35.36	11.65	13.89	16.31	16.88	19.48	22.11	25.10	27.60	30.31	32.07	34.99	37.93
		3	23.08	8.31	9.76	11.32	13.34	15.09	16.83	-	-	-	-	-	-
24	3 1/2	1	52.07	15.36	18.29	21.22	21.66	24.62	27.77	-	-	-	-	-	-
		2	38.91	13.33	15.93	18.56	17.99	20.64	23.47	28.52	31.45	34.38	34.82	37.78	40.93
		3	26.66	9.75	11.50	13.25	14.76	16.59	18.53	-	-	-	-	-	-
26	1	1	27.18	6.98	8.42	9.76	-	-	-	-	-	-	-	-	-
		2	21.43	6.19	7.48	8.71	-	-	-	-	-	-	-	-	-
		3	11.67	3.86	4.59	5.29	-	-	-	-	-	-	-	-	-
26	1 1/2	1	36.23	9.55	11.37	13.22	-	-	-	-	-	-	-	-	-
		2	28.47	8.44	10.10	11.78	-	-	-	-	-	-	-	-	-
		3	16.22	5.41	6.37	7.35	-	-	-	-	-	-	-	-	-
26	2	1	44.86	11.41	13.50	15.61	-	-	-	-	-	-	-	-	-
		2	35.13	10.12	12.03	13.97	-	-	-	-	-	-	-	-	-
		3	20.94	6.68	7.83	8.98	-	-	-	-	-	-	-	-	-
26	2 1/2	1	51.87	14.20	16.75	19.34	-	-	-	-	-	-	-	-	-
		2	40.48	12.50	14.82	17.18	-	-	-	-	-	-	-	-	-
		3	25.24	8.46	9.89	11.34	-	-	-	-	-	-	-	-	-
26	3	1	58.62	15.48	18.07	21.10	23.60	26.62	29.88	-	-	-	-	-	-
		2	45.57	13.67	16.05	18.80	19.96	22.72	25.70	-	-	-	-	-	-
		3	29.72	9.53	11.03	12.78	15.50	17.30	19.24	-	-	-	-	-	-
26	3 1/2	1	65.52	16.69	19.71	22.98	24.48	27.92	31.41	-	-	-	-	-	-
		2	50.75	14.79	17.55	20.52	20.77	23.90	27.09	-	-	-	-	-	-
		3	34.61	10.61	12.41	14.35	16.79	18.89	20.14	-	-	-	-	-	-

(Table 1 continued on next page)

(Table 1 continued)

[illegible]	[illegible]	[illegible]	[illegible]	Diameter growth only (D.b.h. growth-inches)			Diameter growth + 1/2 log grade increase (D.b.h. growth-inches)			Diameter growth + 1 grade increase (D.b.h. growth-inches)			Diameter growth + 1/2 log gr. inc. and 1 grade increase (D.b.h. growth-inches)		
				1.4	1.8	2.2	1.4	1.8	2.2	1.4	1.8	2.2	1.4	1.8	[illegible]
28	1	1	[illegible]	7.94	9.45	10.86	-	-	-	-	-	-	-	-	-
		2	26.85	7.17	8.56	9.88	-	-	-	-	-	-	-	-	-
			[illegible]	[illegible]	5.25	5.99				-			-		-
[illegible]	1 1/2	1	[illegible]	10.68	12.59	14.64	-			-	-	-	-	-	
		2	35.81	9.63	11.41	13.31	-	-	-	-	-	-	-	-	-
			20.42	6.16	7.19	8.29		-	-	-	-	-	-	-	-
[illegible]		[illegible]	[illegible]	[illegible]	15.66	18.32	-	-	-	-	-	-	-	-	-
		2	43.71	11.74	14.16	16.63	-	-	-	-	-	-	-	-	
			26.00	7.71	9.15	10.62	-		-				-		
28	1/2		63.93	15.20	17.88	20.82			-	-	-	-	-	-	-
		-	51.26	13.71	[illegible]	[illegible]				-	-	-	-	-	-
			31.81	9.25	10.78	12.45	-	-	-	-	-	-	-	-	
[illegible]		1	71.28	18.56	21.72	24.91	-	-	-	-	-	-	-	-	-
		2	56.98	16.61	19.55	22.53		-	-	-	-	-	-	-	-
		[illegible]	36.88	[illegible]	13.30	15.17	-	-	-	-	-	-	-	-	-
28	3 1/2	1	79.25	19.87	[illegible]	[illegible]	-	-	-	-	-	-	-	-	-
		2	63.16	17.84	21.18	24.75				-	-	-	-	-	
			42.64	12.65	14.81	17.12	-	-	-	-	-	-	-	-	-
[illegible]		1	39.75	9.10	10.80	12.52	-	-	-	-	-	-	-	-	-
		2	32.87	8.33	9.93	11.56	-	-	-	-	-	-	-	-	-
		3	18.00	5.18	6.08	6.99		-	-	-	-	-	-		
[illegible]	1 1/2	1	[illegible]	[illegible]	14.81	17.08		-	-	-	-	-	-	-	-
		[illegible]	43.84	11.47	13.59	15.74	-	-		-	-	-	-	-	-
		[illegible]	24.98	7.30	8.52	9.76	-	-	-	-	-	-	-	-	
30	[illegible]	1	65.34	15.06	17.38	19.96	-	-	-	-			-	-	-
		-	53.80	13.79	16.02	18.48		-	-	-	-	-	-	-	-
		3	31.91	9.01	10.33	11.78	-	-	-	-	-	-	-	-	-
[illegible]	2 1/2	1	76.14	18.27	21.56	24.88			-	-	-	-	-		-
		[illegible]	62.55	16.67	19.77	22.91	-	-		-	-	-	-	-	-
		[illegible]	38.61	11.15	13.03	14.94	-	-	-	-	-	-	-	-	
[illegible]	[illegible]	1	86.55	19.87	23.65	27.24	-	-	-	-	-	-	-		
		[illegible]	70.93	18.20	21.75	25.16		-	-	-	-	-	-		
		[illegible]	45.56	12.51	14.73	16.86	-		-	-	-	-		-	-
	3 1/2	1	95.61	23.04	26.85	30.93	-	-	-	-	-		-	-	-
		[illegible]	78.16	21.01	24.64	28.51	-	-	-	-	-	-	-	-	-
		[illegible]	52.24	14.78	17.10	19.58	-	-	-	-		-	-	-	-
[illegible]	4	[illegible]	104.31	25.47	29.76	34.30	-	-	-	-	-	-	-	-	-
		2	85.05	23.21	27.27	31.58	-	-	-	-	-	-	-	-	-
		[illegible]	[illegible]	16.74	19.41	22.24	-	-	-	-	-	-	-	-	-

Addition of 1/2-log in merchantable height at the same rates of diameter growth and at the same beginning diameter, merchantable height, and grade, would increase these values by another $4.88, $5.85, and $6.86 over the same 10-year period. In many cases, however, depending on the silvicultural system being used, there may be a potential to increase grade without an increase in merchantable height. If only diameter growth and grade increased, the respective total increases would amount to $8.77, $9.81, and $10.88.

Under optimum conditions over a 10-year period it may be possible to obtain a 1/2-log increase in merchantable length and a 1 grade improvement in addition to the increase in diameter. The expected value increase for the same beginning tree size and grade then would become $11.12, $12.35, and $13.61, according to the rate of diameter growth.

In general, the greatest proportion of the value increase over a 10-year period where diameter growth, merchantable height increase, and grade improvements do occur will accrue from grade improvement (table 2). With a diameter growth of 1.8 inches over 10-years, a 1/2-log height increase, and a 1 grade improvement in a 16-inch, 2-log, butt log grade 2 tree, the 10-year dollar value increase of $12.35 would consist of 44 percent contributed by the grade improvement, 35 percent by diameter growth, 12 percent by the increase in merchantable height, and 9 percent because of a combination effect of diameter, height, and grade change. The value of diameter growth becomes greater than the value of grade improvement only in trees larger than 22 inches in diameter when increases in all factors are still possible. However, height increases are not likely to occur in large diameter but initially short merchantable height trees, and grade improvement is not likely to occur in large diameter trees of the lower grades or in trees that have reached butt log grade 1 (when other products such as veneer are not considered).

Rate of Value Change

The financial maturity concept is based on the earning power or rate of value increase over a given period of time. In small trees, with a low initial value, the addition of a relatively small dollar increase results in fairly high rates of value increase. The rate of value increase tends to decline as the trees become larger (table 3). The primary concern thus becomes the minimum rate of value increase that will be acceptable to the land manager from the large, high value trees and the comparison between trees of acceptable silvicultural characteristics.

Table 2.—*Distribution of dollar value increase of sugar maple for potential increases in diameter, height, and butt log grade over a 10-year period*
(In percent)

	BUTT LOG GRADE 3 TREES											
	Beginning diameter and merchantable height and different 10-year diameter growth rates											
	14"-1 1/2 logs			16"-2 logs			18"-2 1/2 logs			22-2 1/2 logs		
	(D.b.h. growth-inches)			(D.b.h. growth-inches)			(D.b.h. growth-inches)			(D.b.h. growth-inches)		
	1.4	1.8	2.2	1.4	1.8	2.2	1.4	1.8	2.2	1.4	1.8	2.2
	Grade Improvement not Expected											
	12	12	12	14	14	14						
Grade improvement				53	51	49						
Combination effect				5	5	5						
Dollar value increase	1.32	1.47		7.93	8.90	9.91						
	BUTT LOG GRADE 2 TREES											
Diameter growth				32	35	38			42		39	42
(1/2 log)	11	11	11	12	12	12	12	11	11	17	17	16
Grade improvement (1 grade)				47	44					41	38	36
	1	1	1	9	9			7				
Dollar value increase	7.78	8.63		11.12	12.35	13.61		18.16	20.00	25.31	27.81	30.32

Table 3.—*10-year rate of value increase in sugar maple for given increases in diameter, height, and grade*
(In percent)

Present				Diameter growth only			Diameter growth + 1/2 log ht. incr.			Diameter growth + 1 grade incr.			Diameter growth + 1/2 log ht. incr. and 1 grade incr.		
D.b.h. (inches)	Merch.-height (logs)	Butt log grade	Value (dollars)	(D.b.h. growth-inches) 1.4	1.8	2.2	(D.b.h. growth-inches) 1.4	1.8	2.2	(D.b.h. growth-inches) 1.4	1.8	2.2	(D.b.h. growth-inches) 1.4	1.8	2.2
14	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-
		2	1.86	6.1	7.2	8.3	9.2	10.3	11.4	12.1	13.0	13.9	15.5	16.5	17.4
		3	0.29	15.1	16.9	18.5	19.8	21.6	23.2	27.6	28.9	30.2	31.3	32.7	34.0
14	1 1/2	1	-	-	-	-	-	-	-	-	-	-	-	-	-
		2	2.41	6.4	7.5	8.6	8.1	9.2	10.4	12.6	13.5	14.4	14.6	15.5	16.4
		3	0.50	13.5	15.2	16.8	16.6	18.3	19.9	24.4	25.7	27.0	26.3	27.7	29.1
14	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-
		2	2.73	6.7	7.9	9.0	8.3	9.4	10.6	13.1	14.1	15.0	15.0	15.9	16.8
		3	0.73	12.4	14.0	15.5	15.3	16.9	18.4	21.7	23.1	24.4	23.5	24.9	26.1
16	1	1	5.80	3.9	4.7	5.5	-	-	-	-	-	-	-	-	-
		2	3.31	5.1	6.1	7.0	-	-	-	9.9	10.8	11.6	-	-	-
		3	1.04	8.5	9.9	11.1	-	-	-	18.0	19.1	20.2	-	-	-
16	1 1/2	1	7.84	4.0	4.7	5.4	5.9	6.7	7.4	-	-	-	-	-	-
		2	4.40	5.2	6.1	7.1	7.1	8.0	9.0	10.2	10.9	11.7	12.2	13.0	13.8
		3	1.58	8.2	9.4	10.5	11.0	12.2	13.4	16.6	17.6	18.6	18.6	19.7	20.7
16	2	1	9.34	4.1	4.8	5.6	5.7	6.5	7.2	-	-	-	-	-	-
		2	5.14	5.4	6.3	7.3	6.9	7.9	8.8	10.5	11.3	12.0	12.2	13.0	13.8
		3	2.10	7.8	9.0	10.2	10.3	11.5	12.6	15.3	16.3	17.3	16.9	18.0	19.1
16	2 1/2	1	10.98	4.0	4.8	5.5	5.5	6.2	7.0	-	-	-	-	-	-
		2	5.93	5.4	6.4	7.3	6.7	7.7	8.7	10.6	11.4	12.2	12.2	13.0	13.8
		3	2.73	7.4	8.6	9.7	9.7	10.8	11.9	13.9	14.9	16.0	15.3	16.4	17.4
18	1	1	8.54	3.6	4.3	4.9	-	-	-	-	-	-	-	-	-
		2	5.43	4.4	5.2	6.0	-	-	-	8.4	9.1	9.8	-	-	-
		3	2.20	6.3	7.4	8.3	-	-	-	-	-	-	-	-	-
18	1 1/2	1	11.49	3.6	4.2	4.9	-	-	-	-	-	-	-	-	-
		2	7.23	4.4	5.2	6.0	-	-	-	8.5	9.2	9.8	-	-	-
		3	3.21	6.1	7.1	8.0	-	-	-	-	-	-	-	-	-
18	2	1	13.82	3.6	4.2	4.9	5.3	6.0	6.7	-	-	-	-	-	-
		2	8.58	4.5	5.3	6.1	6.1	7.0	7.9	8.6	9.3	10.1	10.4	11.2	11.9
		3	4.17	5.9	6.9	7.8	8.3	9.3	10.3	-	-	-	-	-	-
18	2 1/2	1	16.15	3.7	4.4	5.1	5.0	5.7	6.4	-	-	-	-	-	-
		2	9.90	4.6	5.5	6.3	5.9	6.7	7.8	8.9	9.6	10.3	10.3	11.0	11.7
		3	5.25	5.8	6.8	7.7	7.8	8.7	9.6	-	-	-	-	-	-

(Table 3 continued on next page)

(Table 3 continued)

Present				Diameter growth only			Diameter growth + 1/2 log ht. incr.			Diameter growth + 1 grade incr.			Diameter growth + 1/2 log ht. incr. and 1 grade incr.		
D.b.h. (inches)	Net l.- height (1 gs)	Butt log grade	Value (dollars)	(D.b.h. growth-inches) 1.4	1.8	2.2	(D.b.h. growth-inches) 1.4	1.8	2.2	(D.b.h. growth-inches) 1.4	1.8	2.2	(D.b.h. growth-inches) 1.4	1.8	2.2
18	3	1	18.54	3.6	4.2	4.9	4.6	5.3	6.0	-	-	-	-	-	-
		2	11.21	4.6	5.4	6.2	5.5	6.4	7.2	8.9	9.6	10.3	10.8	10.8	11.4
		3	6.49	5.6	6.4	7.4	7.2	8.2	9.0	-	-	-	-	-	-
20	1	1	12.12	3.2	3.9	4.5	-	-	-	-	-	-	-	-	-
		2	8.34	3.8	4.6	5.3	-	-	-	7.1	7.8	8.4	-	-	-
		3	3.88	5.0	6.0	6.8	-	-	-	-	-	-	-	-	-
20	1 1/2	1	16.12	3.3	3.8	4.5	-	-	-	-	-	-	-	-	-
		2	11.01	3.9	4.6	5.3	-	-	-	7.3	7.9	8.5	-	-	-
		3	5.50	5.0	5.8	6.6	-	-	-	-	-	-	-	-	-
20	2	1	19.50	3.3	4.0	4.6	5.0	5.6	6.3	-	-	-	-	-	-
		2	13.20	4.0	4.8	5.5	5.6	6.4	7.2	7.4	8.1	8.7	9.2	9.9	10.5
		3	7.07	4.9	5.8	6.6	7.1	8.0	8.8	-	-	-	-	-	-
20	2 1/2	1	23.07	3.2	3.9	4.5	4.5	5.1	5.8	-	-	-	-	-	-
		2	15.49	3.9	4.7	5.4	5.1	5.9	6.6	7.4	8.1	8.8	8.8	9.4	10.1
		3	8.89	4.7	5.6	6.4	6.5	7.3	8.2	-	-	-	-	-	-
20	3	1	26.04	3.2	3.9	4.5	4.3	5.0	5.6	-	-	-	-	-	-
		2	17.32	4.0	4.7	5.4	5.0	5.7	6.5	7.5	8.2	8.8	8.7	9.3	10.0
		3	10.64	4.6	5.4	6.2	6.2	7.0	7.8	-	-	-	-	-	-
20	3 1/2	1	28.85	3.3	3.9	4.5	4.0	4.6	5.3	-	-	-	-	-	-
		2	19.00	4.0	4.8	5.5	4.7	5.5	6.2	7.7	8.3	9.0	8.5	9.1	9.8
		3	12.51	4.5	5.3	6.1	5.8	6.6	7.4	-	-	-	-	-	-
22	1	1	16.56	2.9	3.5	3.9	-	-	-	-	-	-	-	-	-
		2	12.10	3.4	4.0	4.5	-	-	-	6.2	6.8	7.2	-	-	-
		3	6.16	4.2	4.9	5.5	-	-	-	-	-	-	-	-	-
22	1 1/2	1	21.93	3.0	3.5	4.0	-	-	-	-	-	-	-	-	-
		2	15.94	3.4	4.0	4.6	-	-	-	6.3	6.8	7.4	-	-	-
		3	8.59	4.2	4.8	5.4	-	-	-	-	-	-	-	-	-
22	2	1	26.92	2.9	3.5	4.0	-	-	-	-	-	-	-	-	-
		2	19.45	3.4	4.1	4.7	-	-	-	6.3	6.9	7.5	-	-	-
		3	11.10	4.1	4.7	5.4	-	-	-	-	-	-	-	-	-
22	2 1/2	1	31.53	3.0	3.4	3.9	4.3	4.8	5.3	-	-	-	-	-	-
		2	22.64	3.4	4.0	4.6	4.7	5.4	6.0	6.4	6.9	7.4	7.8	8.3	8.9
		3	13.68	4.0	4.6	5.1	5.8	6.4	7.0	-	-	-	-	-	-
22	3	1	35.46	3.1	3.6	4.1	4.1	4.6	5.2	-	-	-	-	-	-
		2	25.30	3.6	4.2	4.8	4.5	5.2	5.8	6.6	7.2	7.7	7.6	8.2	8.8
		3	16.18	4.0	4.7	5.2	5.5	6.2	6.8	-	-	-	-	-	-

(Table 3 continued on next page)

(Table 3 continued)

Present				Diameter growth only			Diameter growth + 1/2 log ht. incr.			Diameter growth + 1 grade incr.			Diameter growth + 1/2 log ht. incr. and 1 grade incr.		
D.b.h. (inches)	Merch.-height logs	Butt log grade	Value (dollars)	(D.b.h. growth-inches) 1.4	1.8	2.2	(D.b.h. growth-inches) 1.4	1.8	2.2	(D.b.h. growth-inches) 1.4	1.8	2.2	(D.b.h. growth-inches) 1.4	1.8	2.2
22	3 1/2	1	[illegible]	3.0	3.5	4.1	3.9	4.4	5.0	-	-	-	-	-	-
		2	27.90	[illegible]	4.2	4.8	4.4	5.0	5.7	6.6	[illegible]	7.7	7.5	8.1	8.7
		3	18.87	3.9	4.5	[illegible]	5.2	5.9	6.5	-	-	-	-	-	-
24	[illegible]	[illegible]	[illegible]	2.5	2.9	3.4	-	-	-	-	-	-		-	-
		2	16.62	2.8	[illegible]	3.8	-	-	-	[illegible]	[illegible]	[illegible]	-	-	-
		[illegible]	8.91	3.3	3.8	4.3	-	-	-	-	-	-	-	-	-
[illegible]	1 1 [illegible]	1	28.88	2.5	[illegible]	3.4	-	-	-	-	-	-	-	-	-
		[illegible]	21.98	[illegible]	3.4	3.9	-	-	-	[illegible]	[illegible]	[illegible]	-	-	-
		[illegible]	12.38	3.3	[illegible]	4.3	-		-	-	-	-	-		-
24	[illegible]	[illegible]	35.56	2.6	3.1	3.5	-	-	-	-	-	-			-
		[illegible]	26.95	3.0	[illegible]	4.0	-	-	-	[illegible]	[illegible]	[illegible]	-	-	-
		[illegible]	15.94	[illegible]	3.8	[illegible]	-	-	-	-	-	-	-	-	-
[illegible]	2 1/2	[illegible]	41.01	2.7	3.1	3.6	[illegible]	4.4	[illegible]	-	-	-	-	-	-
		[illegible]	[illegible]	3.0	[illegible]	4.0	4.3	4.8	5.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.8
		[illegible]	19.23	3.3	3.8	[illegible]	5.0	[illegible]	6.0	-	-	-	-	-	-
24	[illegible]	[illegible]	47.09	2.5	[illegible]	[illegible]	3.7	4.1	4.5	-	-	-	-	-	-
		[illegible]	35.36	2.9	3.4	[illegible]	4.0	4.5	5.0	5.5	5.9	6.4	6.7	7.1	7.6
		[illegible]	23.08	[illegible]	[illegible]	4.1	[illegible]	[illegible]	5.6	-	-	-		-	-
24	[illegible]	1	52.07	[illegible]	3.1	3.5	3.5	4.0	4.4	-	-	-	-	-	-
		2	38.91	[illegible]	[illegible]	4.0	3.9	4.4	4.8	5.6	6.1	6.5	6.6	7.0	7.4
		[illegible]	26.66	3.2	[illegible]	4.1	4.5	[illegible]	5.4	-	-	-	-	-	-
[illegible]	[illegible]	1	27.18	[illegible]	2.7	[illegible]	-	-	-	-	-	-	-	-	-
		[illegible]	[illegible]	[illegible]	3.0	[illegible]	-	-	-		-	-	-	-	-
		[illegible]	11.67	2.9	3.4	[illegible]	-	-	-	-	-		-	-	-
[illegible]	1 1/2	1	[illegible]	2.4	2.8	3.2	-		-	-	-		-	-	-
		2	28.47	2.6	[illegible]	3.5	-	-	-	-	-	-	-	-	-
		3	16.22	2.9	[illegible]	[illegible]	-	-	-	-	-	-	-	-	-
26	2	[illegible]	44.86	2.3	[illegible]	3.0	-	-	-	-	-	-	-	-	-
		[illegible]	35.13	2.6	[illegible]	3.4	-	-		-	-	-	-	-	-
		[illegible]	20.94	[illegible]	3.2	3.6	-	-	-	-	-	-	-	-	-
[illegible]	2 1/2	1	[illegible]	2.4	[illegible]	[illegible]	-	-	-	-	-	-	-	-	-
			40.48	2.7	[illegible]	3.6	-	-	-	-	-	-	-	-	-
		[illegible]	25.24	[illegible]	3.4	3.8	-	-	-	-	-		-	-	-
[illegible]	[illegible]	1	[illegible]	[illegible]	2.7	3.1	3.4	3.8	4.2	-	-	-	-	-	-
		[illegible]	45.57	[illegible]	3.1	[illegible]	3.7	4.1	4.6	-	-	-	-	-	-
		[illegible]	29.72	2.8	[illegible]	[illegible]	4.3	4.7	5.1	-	-	-	-	-	-

(Table 3 continued on next page)

(Table 3 continued)

D.b.h.	Merch. height	Log grade	Present value (dollars)	Diameter growth only (D.b.h. growth-inches) 1.4	1.8	2.2	Diameter growth + 1/2 log ht. incr. (D.b.h. growth-inches) 1.4	1.8	2.2	Diameter growth + 1 grade incr. (D.b.h. growth-inches) 1.4	1.8	2.2	Diameter growth + 1/2 log ht. incr. and 1 grade incr. (D.b.h. growth-inches) 1.4	1.8	2.2
26	3 1/2	1	65.52	2.3	2.7	3.1	3.2	3.6	4.0	-	-	-	-	-	-
		2	50.75	2.6	3.0	3.4	3.5	3.9	4.4	-	-	-	-	-	-
		3	34.61	2.7	3.1	3.5	4.0	4.4	4.9	-	-	-	-	-	-
28	1	1	33.21	2.2	2.5	2.9	-	-	-	-	-	-	-	-	-
		2	26.85	2.4	2.8	3.2	-	-	-	-	-	-	-	-	-
		3	14.67	2.7	3.1	3.5	-	-	-	-	-	-	-	-	-
28	1 1/2	1	44.41	2.2	2.5	2.9	-	-	-	-	-	-	-	-	-
		2	35.81	2.4	2.8	3.2	-	-	-	-	-	-	-	-	-
		3	20.42	2.7	3.1	3.5	-	-	-	-	-	-	-	-	-
28	2	1	54.35	2.2	2.6	3.0	-	-	-	-	-	-	-	-	-
		2	43.71	2.4	2.8	3.3	-	-	-	-	-	-	-	-	-
		3	26.00	2.6	3.1	3.5	-	-	-	-	-	-	-	-	-
28	2 1/2	1	63.93	2.2	2.5	2.9	-	-	-	-	-	-	-	-	-
		2	51.26	2.4	2.8	3.2	-	-	-	-	-	-	-	-	-
		3	31.81	2.6	3.0	3.4	-	-	-	-	-	-	-	-	-
28	3	1	71.28	2.3	2.7	3.0	-	-	-	-	-	-	-	-	-
		2	56.98	2.6	3.0	3.4	-	-	-	-	-	-	-	-	-
		3	36.88	2.7	3.1	3.5	-	-	-	-	-	-	-	-	-
28	3 1/2	1	79.25	2.3	2.6	3.0	-	-	-	-	-	-	-	-	-
		2	63.16	2.5	2.9	3.4	-	-	-	-	-	-	-	-	-
		3	42.64	2.6	3.0	3.4	-	-	-	-	-	-	-	-	-
30	1	1	39.75	2.1	2.4	2.8	-	-	-	-	-	-	-	-	-
		2	32.87	2.3	2.7	3.1	-	-	-	-	-	-	-	-	-
		3	18.00	2.6	3.0	3.3	-	-	-	-	-	-	-	-	-
30	1 1/2	1	53.12	2.1	2.5	2.8	-	-	-	-	-	-	-	-	-
		2	43.84	2.4	2.7	3.1	-	-	-	-	-	-	-	-	-
		3	24.98	2.6	3.0	3.3	-	-	-	-	-	-	-	-	-
30	2	1	65.34	2.1	2.4	2.7	-	-	-	-	-	-	-	-	-
		2	53.80	2.3	2.6	3.0	-	-	-	-	-	-	-	-	-
		3	31.91	2.5	2.8	3.2	-	-	-	-	-	-	-	-	-
30	2 1/2	1	76.14	2.2	2.5	2.9	-	-	-	-	-	-	-	-	-
		2	62.55	2.4	2.8	3.2	-	-	-	-	-	-	-	-	-
		3	38.61	2.6	3.0	3.3	-	-	-	-	-	-	-	-	-
30	3	1	86.55	2.1	2.4	2.8	-	-	-	-	-	-	-	-	-
		2	70.93	2.3	2.7	3.1	-	-	-	-	-	-	-	-	-
		3	45.56	2.5	2.8	3.2	-	-	-	-	-	-	-	-	-
30	3 1/2	1	95.61	2.2	2.5	2.8	-	-	-	-	-	-	-	-	-
		2	78.16	2.4	2.8	3.2	-	-	-	-	-	-	-	-	-
		3	52.24	2.5	2.9	3.2	-	-	-	-	-	-	-	-	-
30	4	1	104.31	2.2	2.5	2.9	-	-	-	-	-	-	-	-	-
		2	85.05	2.4	2.8	3.2	-	-	-	-	-	-	-	-	-
		3	59.15	2.5	2.9	3.2	-	-	-	-	-	-	-	-	-

The rate of value increases, while declining in rger trees, becomes higher as trees in the same ameter class grow at faster rates, attain a 2-log increase in merchantable height, or prove in grade. For example, the rate of value crease for a 16-inch 2-log tree, increases from 4 percent to 7.3 percent if the growth rate can be creased from 1.4 to 2.2 inches per decade. here the merchantable length can be increased 1/2-log and quality increased 1 grade, the ee's earning power advances from 12.2 percent to 13.8 percent for the same increase in diameter growth. As noted, however, with the same increases occurring on an 18-inch diameter tree, the rate of value increase would be 10.4 and 11.9 percent although the dollar value increase would be appreciably greater on the larger trees. In large diameter trees, which cannot be expected to increase in merchantable height or grade, only diameter growth can influence the rate of value increase.

Financial Maturity of Sugar Maple

The rate of value increase at which a tree may be considered financially mature depends not only on its physical characteristics of diameter, height, and quality, but finally and decisively on a preselected rate of value increase determined by the owner of the timber. In presenting this coldly calculating method of determining financial maturity, we merely hope to put the fiscal facts before the owner with the understanding that other considerations should be made. We hope to replace the "seat-of-the-pants" decision to harvest the forest crop with a financial determination of tree maturity.

In this study, the "maximum" diameter could range from 15 inches to more than 30 inches as owner-determined return is varied between 2 and 6 percent and depending on grade and height changes that could occur during the 10-year period.

The financial maturity diameter for Grade 2 sugar maple would be 15 inches at a diameter growth of 1.4 inches with no improvement in merchantable height or grade and where the owner objective is 6 percent (table 4). However, if this tree made a 1/2-log increase in merchantable height and an improvement in grade, the financial-maturity diameter increases to 26 inches.

Influence of Other Selling Price-Conversion Cost Combinations

Both lumber selling prices and conversion costs tend to fluctuate because of market and milling changes and commonly cannot be predicted in advance. When lumber selling price and conversion costs remain constant over the projected 10-year period, rather than an increase in lumber selling prices as assumed in "the base calculations", both the expected value increase and the rate of value increase are lower. For example, the expected value increase associated with the constant lumber selling price of $165 over the 10-year period and a constant conversion cost of $70 is only .64 percent of the "the base calculation" value for a 14-inch, 1-log tree growing at a rate of 1.4 inches per 10 years, and the rate of value increase is 1.8 percent lower (table 5).

With either a constant or increasing lumber selling price and a reduction in conversion costs over the 10-year period resulting from improved markets or better mill operations, the expected value and the rate of value increase would be higher than indicated by the base values. For example, with the same lumber selling price change as used in the base value, but a $10 reduction in conversion costs, a 22-inch, 2-1/2-log, butt log grade 2 tree growing at a rate of 2.2 inches in 10-years would show an expected value increase of 138 percent and a rate of value increase of 1.3 percent over the base value. These changes would consequently alter the financial maturity tree diameters.

Application in Marketing

Both the financial maturity concept and the application of silvicultural systems provide for much latitude in managing sugar maple stands. The silvical characteristics of sugar maple, particularly its tolerance to shade, susceptibility to forking that is associated with its opposite-branching habit, and its ability to respond to release, contribute significantly to the potential for change in managed stands. The importance of recognizing economic potential is most critical during the pole and small saw-log stages when differences in rate of diameter growth, merchantable height development, and improvement in butt log grade are fairly apparent and a choice of trees of desirable characteristics is possible. The base values presented in table 1 and 3 thus provide the economic information upon which a silvicultural choice can be made among trees in the marking process.

As a general rule, value increases with tree diameter, merchantable height and grade. In marking, choices most often will be made among various size trees with different potential over the next 10-year period. For example, a 16-inch, butt log grade 2 tree with 1-1/2-logs now could be expected to increase in value $4.29 at a growth rate of 1.4 inches per decade and a 1/2-log merchantable height increase giving a 7.1 percent rate of value increase. If the alternative tree were an 18-inch butt log grade 3, 2-log tree with no potential for increase in height or grade, its expected value increase would be $3.25 at the same rate of growth or a 5.9 percent rate of value increase. The smaller tree would thus be the

Table 4.—*Financial-maturity diameters of sugar maple for selected growth and grade combinations at given rates of value increase*
(In inches)

Butt log grade	Diameter increase (D.b.h. growth-inches)			Diameter and 1/2 log height increase (D.b.h. growth-inches)			Diameter and 1 grade increase (D.b.h. growth-inches)			Diameter and 1/2 log plus 1 grade increase (D.b.h. growth-inches)		
	1.4	1.8	2.2	1.4	1.8	2.2	1.4	1.8	2.2	1.4	1.8	2.2
6 PERCENT RATE OF VALUE INCREASE												
3	18	19	21	21	22	24	No grade increase expected[2]					
2	15	17	19	18	20	22	23	24	25+[3]	26+	26+	26+
1	([1])	([1])	([1])	15	18	20	No grade increase expected[4]					
4 PERCENT RATE OF VALUE INCREASE												
3	22	23	23	27+	28+	28+	No grade increase expected[2]					
2	20	22	24	25	26	28+	28+	28+	28+	28+	28+	28+
1	16	19	22	24	26	27	No grade increase expected[4]					
2 PERCENT RATE OF VALUE INCREASE												
3	30+	30+	30+	30+	30+	30+	No grade increase expected[2]					
2	30+	30+	30+	30+	30+	30+	No grade increase expected[2]					
1	30	30+	30+	30+	30+	30+	No grade increase expected[4]					

[1]Maximum rate of value increase for butt log grade 1 trees is 5.6 percent or lower considering only diameter increase.

[2]Because of large diameter.

[3]+ indicates that diameter will be higher than indicated but is beyond limitations established for analysis.

[4]Maximum grade considered in present study.

Table 5.—*Relative variation in dollar value and rate of value increase from a base to other price-cost combinations, for selected tree sizes and growth rates over a 10-year period*

Lumber selling price	Conversion costs	Butt log grade	Tree size and growth rate: 14"-1 log		22"-2 1/2 log		30"-3 1/2 log		Tree size and growth rate: 14"-1 log		22"-2 1/2 log		30"-3 1/2 log	
Pres.	10 yrs. ago		Pres.	10 yrs. ago	Pres.	10 yrs. ago	Pres.	10 yrs. ago	Pres.	10 yrs. ago	Pres.	10 yrs. ago	Pres.	10 yrs. ago
Base Price-Cost Value			**Value-increase (dollars)**						**Rate of value increase (percent)**					
165	70	1	—	—	10.65	14.69	23.04	30.93	--	--	3.0	3.9	2.2	2.8
		2	1.51	2.26	9.16	12.74	21.01	28.51	6.1	8.3	3.4	4.6	2.4	3.2
		3	0.91	1.32	6.55	8.91	14.78	19.58	15.1	18.5	4.0	5.1	2.5	3.2
Other Price-Cost Combinations			**Percent of base**						**Amount of change from base (percent)**					
165	80	1	—	—	59	66	52	60	—	—	-.9	-.9	-.9	-.8
		2	54	61	59	66	52	61	-.7	-.2	-.8	-.8	-.9	-.9
		3	—	—	52	59	45	53	—	—	-1.0	-.7	-1.0	-1.0
165	70	1	—	—	64	72	56	66	—	—	-1.0	-1.0	-.9	-.9
		2	64	73	65	73	57	67	-1.8	-1.8	-1.0	-1.1	-1.0	-1.0
		3	54	61	61	69	52	61	-4.8	-4.0	-1.4	-1.3	-0.9	-1.1
165	60	1	—	—	70	78	61	71	—	—	-1.1	-1.1	-.9	-.9
		2	75	84	71	79	63	72	-2.4	-2.6	-1.2	-1.3	-1.0	-1.1
		3	70	83	70	78	59	70	-10.0	-10.8	-1.7	-1.7	-1.2	-1.2
165	70	1	—	—	107	105	105	103	—	—	.1	.2	.1	.1
		2	121	115	115	111	110	108	1.0	.9	.5	.4	.2	.2
		3	148	137	131	123	127	121	3.7	3.2	1.0	1.0	.6	.6
165	70	1	—	—	143	133	148	138	—	—	1.0	1.0	.9	1.0
		2	158	143	150	138	153	141	2.5	2.3	1.4	1.3	1.1	1.0
		3	194	173	170	154	175	160	6.4	5.7	2.1	2.1	1.6	1.6

economic choice to leave provided other silvicultural characteristics were similar. Had the larger tree been butt log grade 2 it would be expected to earn a slightly larger dollar value ($4.75) but at a rate of only 4.5 percent. Either value could then be used to guide the timber marker's decision in making the most profitable choice between trees according to the landowner's objective.

In pole-size stands, the predominant size class within the sugar maple types at present, emphasis should be in grade improvement because of its contribution to value increase. The stimulation of diameter growth is strongly associated with grade improvement; however, some sacrifice of diameter growth is often necessary to increase merchantable height through correction of low-forks and to enhance the rate of natural pruning in sugar maple. Once an acceptable merchantable length has been attained, and the potential for grade improvement is achieved, most of the value increase will accrue from increasing the rate of diameter growth.

As previously noted, initial marking will usually be concerned with removal of cull, defective, poor risk (obviously low-grade) trees. In later marking, the emphasis can then be on trees that have potential for grade improvement, those capable of growing at faster rates without reducing grade, and trees that will increase in merchantable height.

The optimum size at which sugar maple trees should be harvested, according to the financial maturity concept, may vary from 15 inches to more than 30 inches in diameter. A final decision must be based in part on the landowner's management and financial objectives and these will in turn be influenced to some degree by the silvicultural system being considered. In uneven-age management, where trees are harvested throughout the diameter range, the largest size will be influenced to a great extent by the recommended stand structure. Under these conditions, with previous selection through all size classes, some large-diameter trees must be maintained even though these few trees per acre may have a rate of value increase slightly lower than desired.

In contrast, in an even-aged system, where all trees are approximately the same size, a high goal could be set for the rate of value increase, resulting in smaller financial-maturity tree diameters and lower value increases. For example, growing 14-inch, 2 log, butt log grade 2 trees at a rate of 2.2 inches for the final 10 years would give a return of 9.0 percent based on diameter growth alone. Should the same trees increase 1 grade, as could be expected because they would reach the minimum diameter for grade 1, the rate of value increase would be 15.0 percent. Holding the trees to larger sizes, i.e., growing 22-inch trees of the same height, grade, and rate of growth for a similar period to attain 24-inch trees at harvest, could yield 7.5 percent with a 1 grade improvement or 4.7 percent for diameter growth alone. If only the dollar value of the tree was considered, the larger trees would show the highest value increase as well as the greatest value at the end of the period.

The financial maturity concept and expected value change should be considered as an additional tool available for making the best choices among trees in managed stands. Where other products or values are involved, other economic approaches should be considered.

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1978. Economic values for growth and grade changes of sugar maple in the Lake States. U.S. Dep. Agric. For. Serv. Res. Pap. NC-155, 16 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

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OXFORD: 852:652.51.176.1 *Acer saccharum* (77). KEY WORDS: financial maturity, value thinning, marking, tree quality, harvest size.

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Put trash in the proper place.

A FOREST SERVICE
EARCH PAPER NC-156

Estimating aspen crown fuels in northeastern Minnesota

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THIS PAPER IS AN EXPERIMENT IN COMMUNICATION.

Realizing that the needs and interests of our two major "clients"—the scientist and the practitioner—are different, we have been concerned whether our publications have been in a form and style equally useful to both. So we have decided to try a new format for some of our Research Papers, one that might serve this dual purpose better.

The Paper is divided into two separate parts: Application and Documentation. The Application section is specifically intended for the man on the ground or in the mill who has a particular job to do or problem to solve. This section describes briefly the situation and the problem, and then goes immediately to the solution, emphasizing the how-to-do-it aspect. It is a complete story in itself; the busy manager need read no further.

The Documentation section describes the details of the research process. It is for the reader interested in laboratory and field procedures, tabulations, statistical analysis, and philosophical discussion. This section, too, is self-contained.

Our purpose is to separate the practical aspects of our research results from the strictly academic ones yet still make both available to all readers. If the practitioner wants to find out how we arrived at our recommendations, the details are in the Documentation section for him to examine. If the scientist has a practical bent, he can turn to the Application section and see the results in action.

It is for you to decide whether we have created a well-matched team or a two-headed monster. *We would like to have your opinion.*

ESTIMATING ASPEN CROWN FUELS IN NORTHEASTERN MINNESOTA

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East Lansing, Michigan

and **Peter J. Roussopoulos,** *Fire Control Scientist,*
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APPLICATION

Tree crowns are an important source of forest fuel, especially as cutting slash or as debris that may follow wind or ice storms. Quaking aspen (*Populus tremuloides* Michx.) is a major constituent of the mature and overmature upland stands in the Boundary Waters Canoe Area of the Superior National Forest. So to appraise the potential flammability of these stands a method was developed to estimate the crown fuel weights of quaking aspen. The tables given in this section were based on the method that is explained in the following Documentation section.

Although the tables below have been designed primarily to be used in fuel models, they could also be used for estimating productivity of potentially usable fiber. The tables can probably be used satisfactorily anywhere in the Lake States, but with the most confidence in northeastern Minnesota.

ESTIMATING DRY WEIGHTS OF FOLIAGE, BRANCHWOOD, AND BOLE TOPS

Use table 1 to get dry weight estimates of foliage, all live and dead branchwood[1] together, and all live branchwood alone, by tree dbh.

[1] *"Branchwood" and also "bolewood" as used in this paper refer to both wood and bark.*

Table 1.—*Dry weight of aspen crown components per tree by d.b.h.*[1]

D.b.h.	Foliage	Live and dead branchwood	Live branchwood
cm		*kg*	
2	0.03	0.1	0.1
4	.15	.5	.3
6	.34	1.3	1.0
8	.62	2.7	2.2
10	1.0	4.8	4.0
12	1.5	7.7	6.5
14	2.0	12.0	9.8
16	2.7	16.0	14.0
18	3.4	22.0	19.0
20	4.3	29.0	25.0
22	5.2	37.0	33.0
24	6.3	47.0	41.0
26	7.4	57.0	51.0
28	8.7	69.0	62.0
30	10.0	83.0	75.0
32	11.5	98.0	89.0
34	13.0	115.0	105.0
36	14.7	133.0	122.0
38	16.5	153.0	141.0
40	18.4	175.0	162.0

[1] Crown branchwood includes bolewood <0.6 cm in diameter. Branchwood and bolewood include all woody parts (wood + bark).

Use table 2 to break down the branchwood tabulations of table 1 into four size classes.

Use table 3 to get dry weights of the bole tops by two size classes. (Weight of bolewood less than 0.6 cm in diameter is given in tables 1 and 2.) These tops are a significant fuel frequently left in the woods following cutting.

Table 2.—*Dry weight of four diameter classes of aspen branchwood per tree by d.b.h.*[1]

D.b.h.	Live and dead branchwood				Live branchwood			
	0-0.6 cm	0.6-2.5 cm	2.5-7.6 cm	7.6+ cm	0-0.6 cm	0.6-2.5 cm	2.5-7.6 cm	7.6+ cm
cm	kg				kg			
2	0.1	0	0	0	0.1	0	0	0
4	.3	0.2	0	0	.2	0.1	0	0
6	.6	.7	0	0	.5	.5	0	0
8	1.0	1.7	0	0	.8	1.4	0	0
10	1.5	3.3	0	0	1.2	2.7	0	0
12	2.1	4.8	0.8	0	1.7	4.0	0.7	0
14	2.8	6.5	2.3	0	2.3	5.4	2.1	0
16	3.6	8.3	4.4	0	3.1	6.8	4.0	0
18	4.4	10.0	7.3	0	3.8	8.6	6.7	0
20	5.2	13.0	11.0	0	4.6	11.0	10.0	0
22	6.3	15.0	16.0	0	5.6	12.0	15.0	0
24	7.5	18.0	21.0	0	6.6	15.0	20.0	0
26	8.6	21.0	27.0	1.1	7.7	17.0	25.0	1.0
28	9.7	24.0	33.0	2.0	8.7	20.0	32.0	1.9
30	11.0	27.0	41.0	3.3	9.7	22.0	39.0	3.7
32	13.0	30.0	49.0	5.9	12.0	25.0	47.0	5.3
34	14.0	34.0	58.0	8.0	13.0	28.0	57.0	7.3
36	16.	39.0	68.0	11.0	15.0	32.0	66.0	9.8
38	17.0	43.0	81.0	12.0	16.0	35.0	78.0	13.0
40	19.0	47.0	93.0	16.0	18.0	39.0	89.0	16.0

[1]Branchwood includes both wood and bark.

Table 3.—*Dry weight of aspen bolewood by size class per tree by d.b.h.*[1]

D.b.h.	Bolewood Diameter Class	
	0.6 - 2.5 cm[2]	2.5 - 7.6 cm
cm	kg	
2	0.27	0
4	.27	1.27
6	.27	1.91
≥8	.27	2.90

[1]Bolewood includes both wood and bark.

[2]Bolewood diameters <0.6 cm are included with branchwood estimates in Table 2.

AN EXAMPLE

The following example summarizes the crown component weight information available from tables 1-3:

An aspen tree 28 cm d.b.h. has been tallied.[2] Table 1 shows the following estimated dry weights:

Foliage	8.7 kg
Live and dead branchwood	69.0 kg
Live branchwood	62.0 kg
Dead branchwood [live & dead (69 kg) minus live (62 kg) = 7 kg]	7.0 kg

Table 2 shows the following estimated d weights:

Diameter class	*Live and dead branchwood*	*Live branchwood*	*Dead branchwood (live & dead minus liv*
(cm)		(kg)	
0 to 0.6	9.7	8.7	1.0
0.6 to 2.5	24.0	20.0	4.0
2.5 to 7.6	33.0	32.0	1.0
7.6 plus	2.0	1.9	0.1
Totals	68.7	62.6	6.1

Table 3 shows the following estimated di weight of bolewood:

Diameter class	*Bolewood*
(cm)	(kg)
0.6 - 2.5	0.27
2.5 - 7.6	2.90
Total	3.17

[2]*English-metric equivalents: 1 inch=2.54 cm; 1 pound=0.4536 kg.*

DOCUMENTION

Methods for estimating aspen crown weights have been developed by a number of investigators: Sando and Wick (1972), and Schlaegel (1975) in northern Minnesota; Zavitkovski (1971) in northern Wisconsin; MacLean and Wein (1976) in New Brunswick, Canada; and Young *et al.* (1964), and Ribe (1973) in Maine. However, these methods fail to distinguish different branchwood size classes, which are needed to predict fire behavior using the Rothermel (1972) model. Sando and Wick (1972) were concerned with "foliage and that portion of the tree smaller than 2.5 inches (6.35 cm) in diameter"—the parts most significant to fire management—but no further size breakdown was attempted.

Suitable methods for estimating crown weights and size distributions of woody materials are now available for most western species (Brown 1976) but are lacking for most eastern ones. The purpose of the present study was to provide a suitable method for quaking aspen.

METHODS AND RESULTS

Field data were collected during August and September of 1976. Fifteen dominant or codominant aspen trees were selected for destructive sampling on the Superior National Forest in Minnesota. Selected trees ranged from 3 to 38 cm in d.b.h.

Tree measurements included diameter at breast height, total height, length and width of live crown, diameters of all branches 5 cm from the bole (basal diameter), and length of dead branches. A total of 75 sample branches (every tenth branch), 47 live and 28 dead, were cut from the sample trees throughout the length of the crowns to obtain a range of branch sizes.

Ovendry weights of foliage, total branchwood, and branchwood within each of three fuel size groups—0 to 0.6 cm, 0.6 to 2.5 cm, and 2.5 to 7.6 cm in diameter—were determined for sample branches. Weights were determined separately for living and for dead material. Factors for converting field green weight to ovendry were obtained from small samples cut from sample branches and oven dried at 105 C. for 24 hours.

Using branch basal diameter as the independent variable, logarithmic regression analysis yielded good relations on live branches for: weights of foliage, total weights of both live and dead wood, weights of live and dead wood by size classes, weight of live wood only, and weight of live wood by size classes (table 4). Similar regressions were run for dead branches using the product of branch diameter times length as the independent variable (table 4). The addition of branch length significantly improved the estimates for dead branches because many dead branches are broken off at varying lengths. All equations were adjusted for logarithmic transformation bias (Baskerville 1972).

Table 4.—*Equations, coefficients of determination, and number of branches sampled, to estimate various dependent variables in aspen crowns*

Dependent Variable	Equation[1]	r^2	Branches
LIVE BRANCHES			
Foliage	$Wf = 10.694\ (Bd)^{2.160}$	.98	58
Total, Both Live and Dead Wood	$Wtb = [illegible]\ (Bd)^{[illegible]}$	.94	58
Live and Dead wood Classes:			
[illegible]	$R_1 = [illegible]\ (Bd)^{[illegible]}$	.84	47
[illegible]	$R_2 = [illegible]\ Bd^{[illegible]}$	.69	24
[illegible]	$R_3 = 11.107\ (Bd)^{1.205}$	1.	3
Total, Live Wood Only	$Wtb = 25.312\ (Bd)^{2.786}$	.97	58
Live Wood Classes:			
[illegible]	$R_1 = [illegible]\ Bd^{[illegible]}$	.91	[illegible]
[illegible]	$R_2 = 2.194\ (Bd)^{-.877}$	.84	[illegible]
[illegible]	$R_3 = 11.419\ (Bd)^{1.218}$	1.	[illegible]
DEAD BRANCHES			
Total Branchwood	$Wtb = 39.547\ (Bd1)^{1.325}$	.91	[illegible]
Branchwood Classes:			
[illegible]	$R_1 = [illegible]\ (Bd1)^{[illegible]}$	.34	[illegible]
[illegible]	$R_2 = 1.159\ (Bd1)^{-.253}$	.83	11

[1]The abbreviated terms are:
Bd = Branch basal diameter, centimeter
Bd1 = Branch basal diameter in centimeters times branch length in meters
Wf = Foliage weight, grams
Wtb = Total branchwood weight, grams
R_1, R_2, R_3 = Ratio of branchwood within a group to total branchwood weight

The size class distribution of branchwood weight for individual branches is represented by estimating the ratio of branchwood weight in each size class to total branchwood weight per branch. Since more than 100 percent of a branch cannot be attributed to a size class (a ratio greater than one), the size class regressions for live branches apply only when the branch diameter is larger than $a^{-1/b}$; where "a" and "b" are the regression coefficients of the appropriate size class equation $R_i = a(\text{Basal diameter})^b$ (table 4). For example, the 0- to 0.6-cm size class equation for "live

wood'' applies only to branches with basal diameters greater than 0.56 cm. Below this ''critical diameter'' the entire branch is within the 0- to 0.6-cm size class, and the ratio contribution is therefore 1.0. In general:

$$R_i = \begin{cases} a(\text{Basal diameter})^b, & \text{Basal diameter} \geq a^{-1/b} \\ 1.0, & \text{Basal diameter} < a^{-1/b} \end{cases} \quad (1)$$

Similarly, for dead branches:

$$R_i = \begin{cases} a(\text{Branch diameter times length})^b, & \text{Branch diameter times length} \geq a^{-1/b} \\ 1.0, & \text{Branch diameter times length} < a^{-1/b} \end{cases} \quad (2)$$

The equations developed for branches were then used to ''build'' crowns for the 15 sample trees using the respective tallies of branch diameters—and for dead branches—branch lengths. Equations were developed for the weight of foliage alone, foliage and branchwood, live branchwood, and total branchwood using tree dbh as the independent variable (table 5). Additionally, equations were developed to compute ratios of branchwood size-class weights to totals (table 6). Again, these equations are constrained at a value of 1.0 for low dbh trees.

Our crown branchwood estimates include the very topmost section of the bole 0.6 cm in diameter and smaller. Because it is a significant fuel and often left in the woods after cutting, estimates of bolewood within the 0.6- to 2.5- and 2.5- to 7.6-cm diameter classes were prepared separately (table 3). These estimates were based on our data for another study for northern red oak trees, (adjustments for differences in wood specific gravity were made), and on Schlaegel's (1975) estimating methods for weight of boles and the percentage of bolewood within specific diameter ranges for aspen.

DISCUSSION

Our definition of live branchwood is compatible with that of Schlaegel (1975) and Zavitkovski (1971), but they use a second estimator—tree

Table 5.—*Coefficients, standard deviations, coef ficients of determination, and number o samples used in estimating dry weights o aspen crown components*[1]

Dependent Variable	a	b	$S_{y \cdot x}{}^2$	r^2	n
Total Weight	0.0182	2.5094	0.237	0.98	15
Foliage Weight	.0079	2.1012	.264	.97	15
Live Branchwood Weight	.0084	2.6746	.307	.98	15
Total Branchwood Weight	.0125	2.5874	.233	.98	15

[1]Weight (kilograms) per tree by dbh (centimeters), and the general equation $Y = aX^b$.

[2]$S_{y \cdot x}$ (standard deviations about regression) in terms of natural logarithmic values of the variates according to the general form $\ln Y = a + \ln X$ before adjustment for bias.

Table 6.—*Coefficients, standard deviations, coef ficients of determination, and number o samples used in estimating the ratio of weigh of aspen branchwood per size class to tot branchwood weight*[1]

Dependent variable weight size-class branchwood/ weight total branchwood	a	b	$S_{y \cdot x}{}^2$	r^2	n
LIVE AND DEAD BRANCHWOOD					
0 to 0.6 cm/Total	1.856	-0.773	0.132	0.95	15
0 to 2.5 cm/Total	5.317	- .718	.128	.88	13
0 to 7.6 cm/Total	1.793	- .185	.015	.87	6
LIVE BRANCHWOOD					
0 to 0.6 cm/Total	1.846	- .771	.146	.94	15
0 to 2.5 cm/Total	6.249	- .784	.132	.89	13
0 to 7.6 cm/Total	1.892	- .202	.015	.88	6

[1]Ratio of weights (kilograms) per tree by d.b.h. (centimeters), and the general equation $Y = aX^b$.

[2]$S_{y \cdot x}$ (standard deviations about regression in terms of natural logarithmic values of the variates according to the general form $\ln Y = a + b \ln X$ before adjustment for bias.

height—in their equations. Using the measur heights and diameters for our sample tree though, we were able to compute estimates branchwood weight, and foliage weight, for ea tree both by Schlaegel's and by Zavitkovsk equations and compare them with our estimat (fig. 1). Our branchwood estimates were similar Schlaegel's for Minnesota trees up to about 28 d.b.h., beyond which ours became increasing heavier. Zavitkovski's branchwood equatio developed for his Wisconsin trees, produc estimates much lower than found for c Minnesota sample, and a similar relation w found when foliage estimates were compare Results of a Russian study by Zukova (1969) w also examined. The weight of live branchwood 6 aspen trees in the Moscow region was found, the most part, to fall closer to the Minnesota th to the Wisconsin estimates (fig. 1).

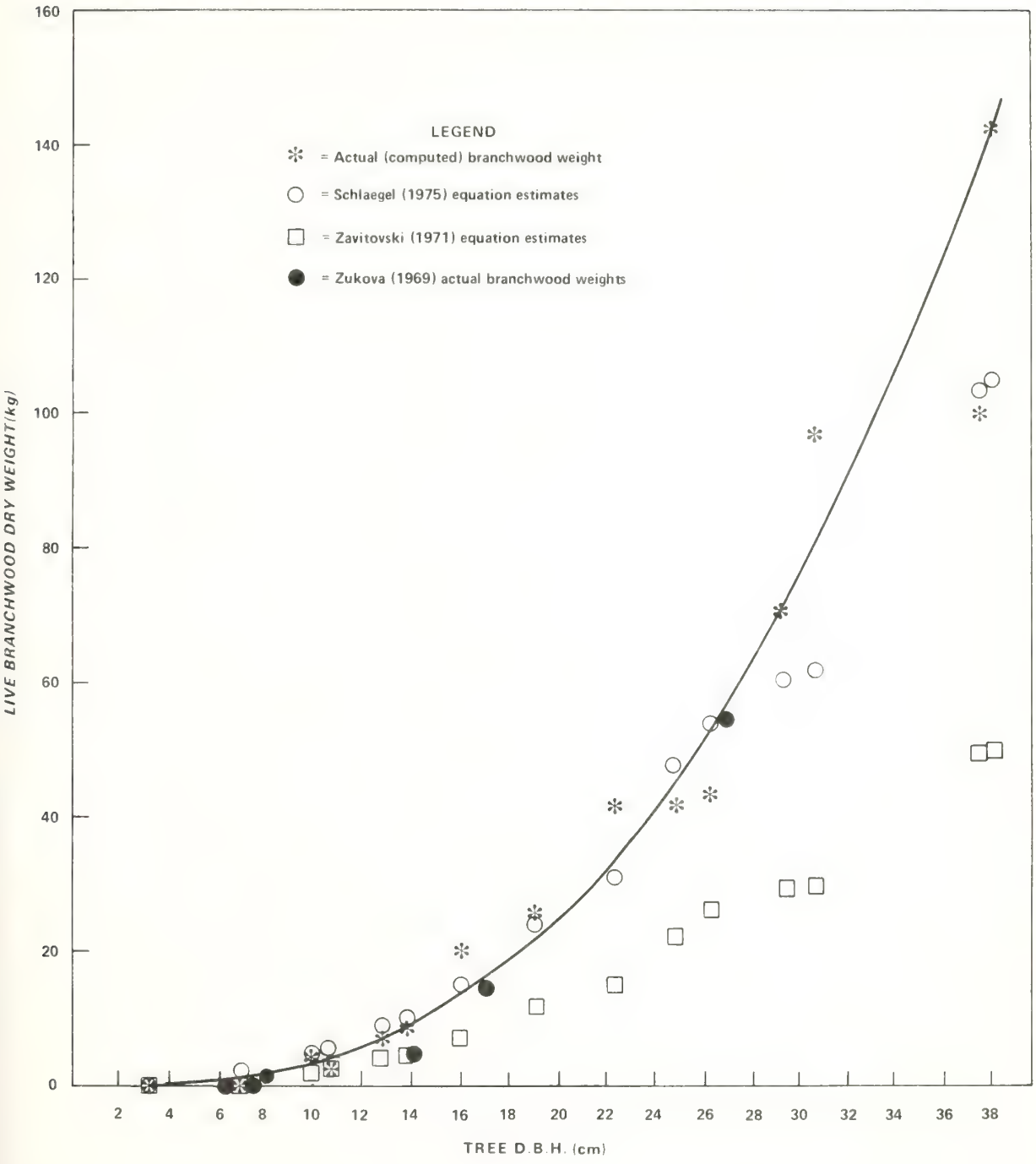

Figure 1.—*Actual live branchwood weights plotted over tree dbh compared with those of Zukova* (1969), *and with Schlaegel's* (1975) *and Zavitkovski's* (1971) *equation estimates. The prediction curve is based on the actual weights. (Data from 15 northeastern Minnesota quaking aspen trees.)*

We compared our estimates of live branchwood with estimates for Maine trees using equations by Young *et al.* (1964) and by Ribe (1973). We also compared aspen crown weights (branches and leaves) estimated by an equation by MacLean and Wein (1976) for New Brunswick, Canada, with our live branchwood plus leaves. These investigators used dbh as the estimator. All three of these estimates were much below ours, as were those of Zavitkovski for branchwood and for foliage.

The estimates by the various investigators may be influenced by several factors, including climate, site, and stand density. The basic data used by Zavitkovski indicates that stand density may strongly influence the estimates. For example, his regression equation was controlled by 48 trees, all from dense stands and less than 20 cm d.b.h. However, two larger sample trees, 24 and 29 cm d.b.h. both from low density stands had actual branchwood weights within the range of the predictions of the Minnesota equations.[3] Our trees were from medium to low density stands; the larger trees particularly had little crown competition.

All our sample trees were quaking aspen. Zavitkovski (1971), however, having sampled both quaking and largetooth aspen (*Populus grandidentata* Michx.), found no obvious difference between the species in the distribution of dry weight among components. This supports the use of our equations for both species.

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[3]*Personal communication with J. Zavitkovski, Institute of Forest Genetics, Rhinelander, Wisconsin, September 9, 1977.*

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Structure and biomass production of 1- to 7-year-old intensively cultured jack pine plantation in Wisconsin

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STRUCTURE AND BIOMASS PRODUCTION OF 1- TO 7-YEAR-OLD INTENSIVELY CULTURED JACK PINE PLANTATIONS IN WISCONSIN

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and **David H. Dawson,** *Principal Plant Geneticist,*
Rhinelander, Wisconsin

New silvicultural practices will have to be troduced into United States forests to respond to ıe demand for fiber that is expected to double by ıe year 2000 (Auchter 1976). The Maximum Yield ıd Intensive Culture Project was established at ıe Institute of Forest Genetics in Rhinelander, Visconsin, with the mission to study a short-rota- on intensive culture (SRIC) system. In the SRIC ystem, agrotechniques, which greatly increased roduction of agricultural crops, are applied to orestry. Selected or improved tree species or ybrids are planted at close spacings and grown ı short rotations under intensive care including te preparation, weed control, fertilization, and rigation. Results of previous studies on *Populus* ybrids indicated that biomass production in SRIC lantations can be significantly increased in omparison to the production achieved in planta- ons or natural stands tended in the traditional ay (Dawson *et al.* 1976, Ek and Dawson 1976).

The objectives of this study were to evaluate the uitability of jack pine (*Pinus banksiana*) for the RIC system in the Lake States and to identify a ombination of spacing and rotation at which the ıean annual biomass production of stems and ranches reaches its maximum. Jack pine was ıcluded in the SRIC studies because of its rapid uvenile growth and desirable wood properties for ulp and paper production.

METHODS AND MATERIALS

The plantations were established in 1970 at Rhinelander, Wisconsin, using tubelings grown from seed collected in southern Michigan. The seedlings were grown in plastic tubes in a greenhouse for 5 months and outplanted in June 1970. They averaged about 5 cm in height at the time of planting and, in spite of adequate irrigation and fertilization, grew only about 1 cm during the first growing season in the field. It became obvious that the plastic tubes restricted root development and seedling growth so the plastic tubes were removed in September 1970. Height growth in the second year improved but at age 2 the average height was at least 1 year behind in comparison to freely-developing seedlings raised under less intensive conditions (Jeffers and Nienstaedt 1973).

The plantations were established at 9- by 9-, 12- by 12-, and 24- by 24-in. spacings in plots 16 by 16 ft. in size. Each spacing was replicated three times. A 10-ft. wide weedless open space was left between replications and a 6-ft. wide open space was left between plots within each replication. A high level of soil nutrients was maintained by annual fertilization and soil moisture was kept near field capacity by irrigation, which was

gauged according to the weather. In 1976 (an extremely droughty year), the irrigation had to be reduced to once a week (about 1/3 of the regular amount) and in mid-July it was discontinued.

During the first 3 years, heights and basal diameters (1 in. above ground) were measured on 150, 90, and 30 seedlings in plantings spaced 9- by 9-, 12- by 12-, and 24- by 24- in., respectively. At age 4 and 5, heights and diameter breast height (dbh) were measured on 54, 36, and 9 trees, and at age 6 and 7, on more than 300, 200, and 50 trees in the same spacings.

From 4 to 7 years, dry weights of tree components—stems, branches, needless, wood, and bark—were obtained on sample trees. At age 4 and 5, sample trees were harvested from a subplot in each plot, then dry weights of tree components were obtained for the subplot, and biomasses per hectare were calculated. Biomasses at ages 6 and 7 were obtained by regression techniques (allometry) (Zavitkovski *et al.* 1974). Briefly, dbh's were measured and the trees divided into three dbh classes. A sample of nine trees, one from each dbh class in each replication, was taken from plantings at each spacing at age 6 and a sample of three trees at age 7. All harvested trees were separated into stems, branches, and needles, dried at 70 C to a weight equilibrium, and weighed. Percentages of wood and bark in stems and branches, and percentages of current year's, older living, and dead branches and needles were obtained on three trees in each spacing. The allometric (double-logarithmic) (Zavitkovski 1971) and double-square-root (Schreuder and Swank 1973) growth models were fitted to the weight data with *dbh* or $(Dbh)^2$ *x height* as the independent variables. The biomass of each tree (or tree component) in each plot was calculated from the allometric regressions and the stand biomass obtained by the method of "every-tree-summation" (Baskerville 1965). All measurements and destructive sampling were done during the dormant season. Biomasses at ages 1 to 3 were approximated from allometric regressions between height and dry weight of 4-year-old seedlings.

The current annual increment (c.a.i.) of total tree or stem plus branch biomass refers to living trees only and was obtained by subtracting the biomass at age t from the biomass at age $t + 1$. The current annual production (c.a.p.) is define as c.a.i. plus the biomass of trees that died durin the year. The mean annual increment (m.a.i.) total tree or stem plus branch biomass refers living trees only and was obtained by dividing th biomass by current age. The mean annu production (m.a.p.) was obtained in the sam manner as the m.a.i. but included the biomass standing dead trees. The total or whole tre biomass refers to the above-ground parts of tre only.

Biases are inherent in studies on bioma production on small experimental forest plan ings. The "edge effect" extended through sever rows in all plots and was more severe in the den plantings. In 1976 mortality percentages in rows (border row), 2, 3, 4, and 5 through 11 of the 9 9-in. planting were 11, 23, 37, 41, and 59 percen Diameters at breast height in the same rows we 23.3, 18.1, 18.1, 18.2, and 17.3 mm. Le pronounced gradients of mortality and d occurred in the 12- by 12- and 24- by 24- plantings. The bias in production statistics w reduced by excluding rows 1 and 2 in the 9- by and 12- by 12-in. planting and row 1 and the 24- 24-in. planting.

RESULTS AND DISCUSSION

Spacing and Height Growth

Height growth during the first 2 years w extremely slow because of the restrictive effec plastic tubes on seedlings development. At time of planting, the seedlings were 5 cm in hei and they reached only 6 cm at the end of the f growing season and 17 to 19 cm at the end of second (fig. 1). In genetics tests conducted in same area by Jeffers and Nienstaedt (19 2-year-old jack pine averaged 50.1 cm. Our pla reached that height at age 3.

Our plants grew rapidly from age 2 to 7. By 4 they were about 30 percent taller than f planted jack pine in Michigan (Canavera Wright 1973); by age 5 they were about 50 t percent taller than jack pine from Ont (Yeatman 1974); by age 6 they equalled the he of 10-year-old plantations in lower Michi

Guilkey and Westing 1956); and at age 7, they were about as high as 12-year-olds in Wisconsin, Michigan, and Minnesota (King 1966). The average height of the 24 x 24-in. planting (3.50 m) approached that of a 15-year-old Michigan plantation established at 18 x 18-in. spacing (Guilkey and Westing 1956).

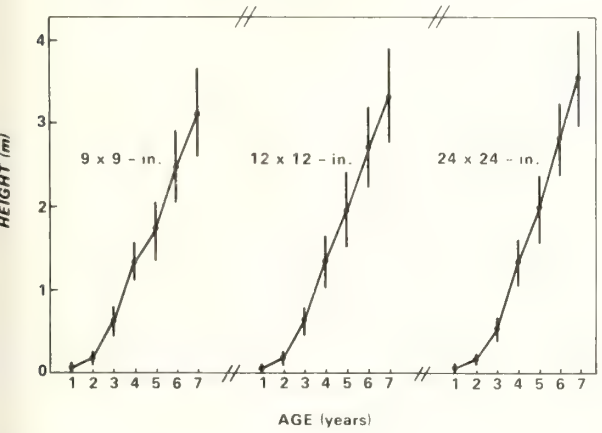

Figure 1.—*Height growth of 1- to 7-year-old jack pine at three spacings. Vertical bars indicate - standard deviation.*

The effect of spacing on height growth showed up at age 5 and became significant at age 7 when the average height was 3.10, 3.31, and 3.50 m in planting spaced 9- by 9-, 12- by 12-, and 24- by 24 in., respectively (table 1, fig. 1). However, the average height of dominant trees (3.50 m or more) in each planting—3.76, 3.81, and 3.85 m—was not significantly different. The same structural pattern was observed by Guilkey and Westing (1956) in 15-year-old plantations of jack pine in Michigan. Whereas the average height of all living trees in the densest planting (18- by 18-in.) was about 2 ft. less than in more widely-spaced plantings, the average height of dominant trees was about the same in all spacings.

The same height distribution pattern was also present in 15-year-old jack pine plantations established at four densities in Wisconsin (Wilde *et al.* 1968). The average height of the densest planting (24- by 24-in.) was about 2 ft. less than in plantings established at wider spacings. Wilde and coworkers ascribed that depression to a critical shortage of soil moisture. It seems, however, that the depression in height may have resulted from a competition light rather than for soil moisture. This point is supported by our studies in which soil moisture stresses were eliminated by irrigation. A severe competition for light was obviously the main reason for height growth depression in the 9- x 9-in. planting compared to the average height in the 24- x 24-in. planting.

Spacing and Diameter Growth

The basal and breast height (dbh) diameter growth increased with increased spacing (fig.2). At age 5 the dbh averaged 0.71, 0.97, and 1.16 cm in the 9- by 9-, 12- by 12-, and 24- by 24-in. spacing, respectively. The dbh doubled during the 6th year but then the increase slowed down during the 7th. The shape of the dbh curve for the 24- by 24-in. planting suggests a continuous steep increase in future years whereas dbh increases in the 9- by 9- and 12- by 12-in. plantings are likely to be small. The variability of dbh's was high and was especially high in the denser plantings where the competition for space was more severe.

Table 1.—*Structure and biomass yields of 7-year-old jack pine*

Spacing	Stand density		Survival	Average height	Average dbh	Total dry weight	Stem		Branches		Needles	Other[1]
	Initial	Age 7					Wood	Bark	Wood	Bark		
Inches	*Trees/ha (Thousands)*		*Percent*	*m*	*cm*	*mt/ha*						
9 by 9	191.3	93.7	49	3.10[a2] (0.52)[3]	1.74[a] (0.75)	47.39[a] (5.26)	21.90	6.21	5.48	3.60	9.89[a] (0.69)	0.31
12 by 12	107.6	73.5	68	3.31[b] (0.58)	2.04[b] (0.84)	56.77[a] (6.58)	25.60	6.32	7.54	4.92	12.07[b] (1.44)	0.32
24 by 24	26.9	25.2	94	3.50[c] (0.56)	2.96[c] (0.99)	53.02[a] (13.16)	21.28	4.36	10.43	3.53	12.95[b] (3.72)	0.47

[1]Cones, buds, etc.
[2]Values (in columns) followed by the same letter are not significantly different (p=0.05).
[3]Standard deviation.

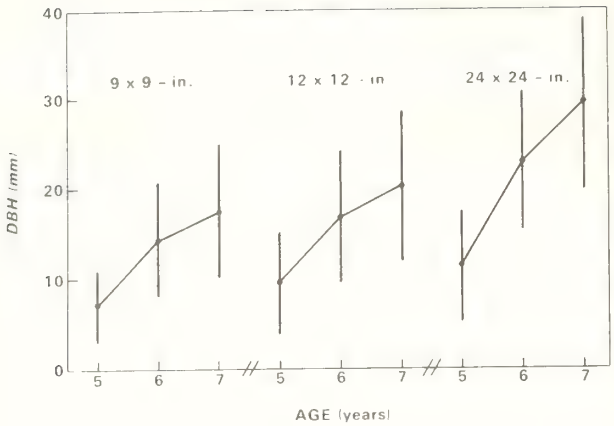

Figure 2.—*Dbh growth of 5- to 7-year-old jack pine at three spacings. Vertical bars indicate - standard deviation.*

Diameter growth was more affected by spacing than was height growth. At age 7, the difference between heights in the 9- by 9- and 24- by 24-in. spacings was about 13 percent and was about 70 percent between dbh's (table 1). The same holds for several other studies dealing with the effects of spacing on growth (Rudolf 1951, Guilkey and Westing 1956, Wilde *et al.* 1968).

At age 6, dbh's of our plantings were comparable to dbh's of 10-year-old jack pine stands in lower Michigan (Rudolf 1951); and at age 7, the average dbh of our 24- by 24-in. planting (2.96 cm) was greater than the dbh of a Michigan 18- by 18-in. planting at 15 years (Guilkey and Westing 1956). At age 10, the dbh of our 24- by 24-in. planting will probably surpass the average dbh (4.6 cm) of 15-year-old jack pine planted at 18- by 18- and 24- by 24-in. in Wisconsin (Wilde *et al.* 1968) or Michigan (Guilkey and Westing 1956).

Spacing and Tree Slenderness

One important tree characteristic that depends both on height and diameter is the slenderness ratio or taper (Assmann 1970). Rudolf (1951) showed that the slenderness index (height in feet divided by dbh in inches) of 10-year-old jack pine trees decreased with increasing spacing from 11.5 in a 18- by 18-in. spacing to 6.5 in a 9- by 9-ft. spacing. The slenderness index in our study followed the same trend and at age 7 was 14.8, 13.5, and 9.9 in the 9- by 9-, 12- by 12-, and 24- by 24-in. plantings, respectively. The trend remained the same for the dominant trees but values for the same spacings were lower — 11.8, 11.6, and 9.1—which indicates that the dominant trees tapered more rapidly. In traditional forestry a low slenderness index is undesirable (Assmann 1970) but it is difficult to assign a significance to the slenderness ratio in the SRIC system.

Spacing and Survival

Survival increased with increasing spacing (tables 1 and 2). About 49, 68, and 94 percent o plants were still alive at age 7 in the 9- by 9-, 12 by 12-, and 24- by 24-in. plantings, respectively During the 7th year the survival decreased b about 7 percent in the two denser plantings bu remained the same in the 24- by 24-in. planting At age 7, the survival in the 12- by 12- and 24- b 24-in. plantings was comparable to the survival c a 10-year-old jack pine plantation established a 18- by 18-in. spacing in lower Michigan (Rudo 1951). However, the survival in the 24- by 24-in planting was much higher than the survival in 15-year-old jack pine plantation of the sam spacing in Wisconsin (Wilde *et al.* 1968). The db and height of this 15-year-old plantation wer reached at age 9 under the intensive cultur system. If the two systems are comparable, mor than 40 percent of the trees in our 7-year-old, 2 by 24-in. planting will die in the next years—unless the irrigation and fertilization ca compensate for the inadequate light.

Table 2.—*Jack pine survival per hectare*

Age	Spacing (inches)					
	9 by 9		12 by 12		24 by 24	
			Percent			
1	191,300	100	107,600	100	26,900	10
2	n.a.[1]	n.a.	n.a.	n.a.	26,900	10
3	n.a.	n.a.	n.a.	n.a.	26,900	10
4	160,900	84	104,600	97	26,900	10
5	142,700	75	101,600	94	26,900	10
6	106,800	56	80,500	75	25,200	9
7	93,700	49	73,500	68	25,200	9

[1] Not available.

We can only speculate on the reasons f mortality in our plantings. Inadequate light, s moisture, and nutrients are frequently cited as t cause of death (Baker 1950, Kramer a Kozlowski 1960, Cooper 1961). In irrigated a fertilized plantations the inadequate light may solely responsible for the death of the underst saplings. On a sunny day, light under canop averaged only 27, 23, and 23 foot-candles in the by 9-, 12- by 12-, and 24- by 24-in. plantin

espectively, which is below the photosynthetic ompensation point.[1]

Spacing and Stand Structure

The main structural distinction between the tand spaced 9- by 9-in. and the one spaced 24- by 4-in. is the number of small understory trees in he denser planting. These trees may live for several years but their position under canopies nd the small amount of light under canopies eave no doubt about their eventual fate. Heights f the dominant trees in all three spacings were bout the same, but dominant tree density was igher in the two denser spacings. At age 6, the umber of dominant trees was 259, 345, and 137 er 100 m^2 in the 9- by 9-, 12- by 12-, and 24- by 4-in. plantings, respectively. By age 7, the umber of dominants had decreased by 22 and 25 n the 9- by 9- and 12- by 12-in. plantings, espectively, but had remained the same in the 24- y 24-in. planting. It appears that the number of ominant trees in the three spacings is converg- ng. The same structural development trend was ound by Sorensen (1968) in aspen stands.

Spacing and Weight of Individual Trees

The average tree weight as well as weights of all tree components—stems, branches, and nee- dles—increased with increasing spacing. At age 7, the average weight of whole trees was 510, 770, and 2,100 g in the 9- by 9-, 12- by 12-, and 24- by 24-in. plantings, respectively.

At age 4, our seedlings were 3 to 12 times heavier than jack pine of the same age grown at wider spacings (Logan 1966). Our plants averaged 166, 240, and 606 g at 4 years and 420, 610, and 1,690 g at 6 years in the 9- by 9-, 12- by 12-, and 24- by 24-in. spacings, respectively.

Dry weight distribution among tree components f Logan's 6-year-old plants indicated their pen-grown condition and their more juvenile haracter in comparison to our plants. Stems, branches,and needles accounted, respectively, for 28, 29, and 43 percent of the above-ground biomass in Logan's plants and for 40, 30, and 30 ercent in our 24- by 24-in. planting and 54, 22, and 24 percent in our 9- by 9-in. planting Zavitkovski and Dawson 1977).

[1]*Zavitkovski, J. Unpublished data on file at the Institute of Forest Genetics, Rhinelander, Wisconsin.*

Spacing and Biomass Growth Models

An allometric model (based on dbh) was used to calculate stand biomasses. Graphed data revealed no difference in relations between dbh and dry weight of tree components from the 9- by 9- and 12- by 12-in. plantings so their data were pooled; the relations were different for trees from the 24- by 24-in. so their data were handled separately. The 1975 and 1976 data within each spacing were also pooled because no significant differences were found between regression coefficients (table 3).

The variance of dry weight was low in regressions between dbh and whole tree and stem biomass but it was high for branches and needles (table 3). The test of additivity of biomass (i.e., comparing, for a given dbh, the whole tree biomass with the sum of stem, branch, and needle biomasses) was excellent for regressions from the 9- by 9- and 12- by 12-in. plantings (less than 1 percent difference) and good for regressions from the 24- by 24-in. planting (less than 2 percent difference).

The regressions indicated that trees with the same dbh from the 24- by 24-in. planting had a greater branch and needle biomass for the entire range of dbh values, a greater total biomass for most of the dbh range and a greater stem biomass for trees with a dbh larger than 19 mm, than trees from the 9- by 9- and 12- by 12-in. plantings.

The regressions for the 6- and 7-year-old trees are not strictly comparable with regressions for older jack pine trees. Slopes of our regressions for trees from the 24- by 24-in. planting paralleled slopes of regressions presented by Crow (1971) for 50-year-old jack pine in Minnesota, by Hegyi (1972) for 11- to 65-year-old jack pine in northern Ontario, and by Doucet *et al.* (1976) for 41- to 46-year-old jack pine in Quebec. However, for the same dbh within the overlapping parts of the regressions, our trees and individual tree components were heavier. The difference was particularly great for branches and needles. Our regressions for trees from the 9- by 9- and 12- by 12-in. plantings had different slopes and could not be compared with other data.

Table 3.—*Coefficients of allometric regression equations for dry weight*

Spacing	Tree Component	Trees	Regression Coefficients[1] a	b	R^2	$S_{y.x}$	Correction factor[2]
Inches		*Number*					
9 by 9 and 12 by 12	Whole Tree	24	0.8472	1.8856	0.9645	0.1618	1.0132
	Stems	24	.6040	1.7727	.9728	.1324	1.0088
	Branches	24	-1.2677	2.0430	.8874	.3257	1.0545
	Needles	24	-1.1374	2.0566	.9216	.2681	1.0366
24 by 24	Whole Tree	12	0.3336	2.1891	.9411	.2124	1.0228
	Stems	12	-0.4888	2.1936	.9767	.1311	1.0086
	Branches	12	-1.7690	2.4279	.8832	.3424	1.0604
	Needles	12	-0.4321	2.0175	.8859	.3166	1.0419

[1]$y=a + b\ x$ where y = ln (dry weight) and x = ln (d.b.h.).
[2]According to Baskerville (1972).

Spacing and Biomass Production

During the first 3 years, biomasses were approximated from average heights and densities using regressions between height and dry weight of 4-year-old plants. Biomasses per unit area were estimated by harvesting subplots at ages 4 and 5 and by regression techniques at ages 6 and 7.

Total Above-Ground Biomass and M.a.i.

The above-ground biomasses at ages 1 to 5 decreased with increased spacing—they were highest in the 9- by 9-in. planting and lowest in the 24- by 24-in. planting (fig. 3). The total biomass of the 12- by 12-in. planting at age 6 and that of the 24- by 24-in. planting at age 7 surpassed the biomass of the 9- by 9-in. planting. The shape of the total biomass accumulation curves (fig. 3) as well as the m.a.i. (fig. 4) and c.a.i. (fig. 5) of stems and branches indicate that in a few years the 24- by 24-in. planting will have the highest total biomass, m.a.i., and c.a.i.

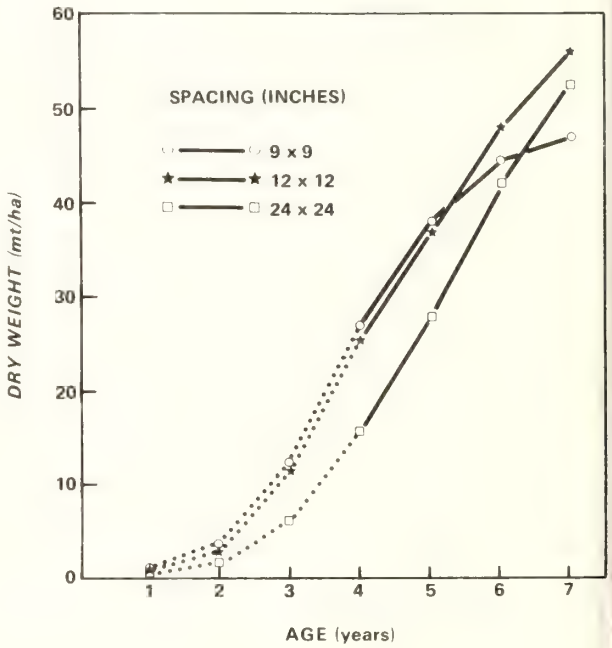

Figure 3.—*Total tree biomass of 1- to 7-year-old jack pine at three spacings.*

At age 7, the total biomass averaged 47.4, 56.8, and 53.0 mt/ha (table 1) and the total m.a.i. was 6.8, 8.1, and 7.6 mt/ha/year (table 4) in the 9- by 9-, 12- by 12-, and 24- by 24-in. plantings, respectively. The total m.a.i. in the 9- by 9-in. planting peaked at age 5 and at age 6 in the 12- by 12-in. stand. It seems unlikely that the total m.a.i. in either planting would increase in the future because each has an excessive number of suppressed and semisuppressed trees that will die in a few years.

The total m.a.i. of our planting was substantially higher than m.a.i.'s reported for jack pine. The highest total m.a.i. in 41- to 46-year-old jack pine in Quebec was about 2.5 mt/ha/year (Douce *et al.* 1976) and in less than 20-year-old jack pin in Ontario was 3.4 mt/ha/year (Hegyi 1972).

The total m.a.i. of our jack pine plantings i comparable to m.a.i.'s reached in stands o various pine and other coniferous species (tabl 5). It is true that SRIC and traditional silvicultur

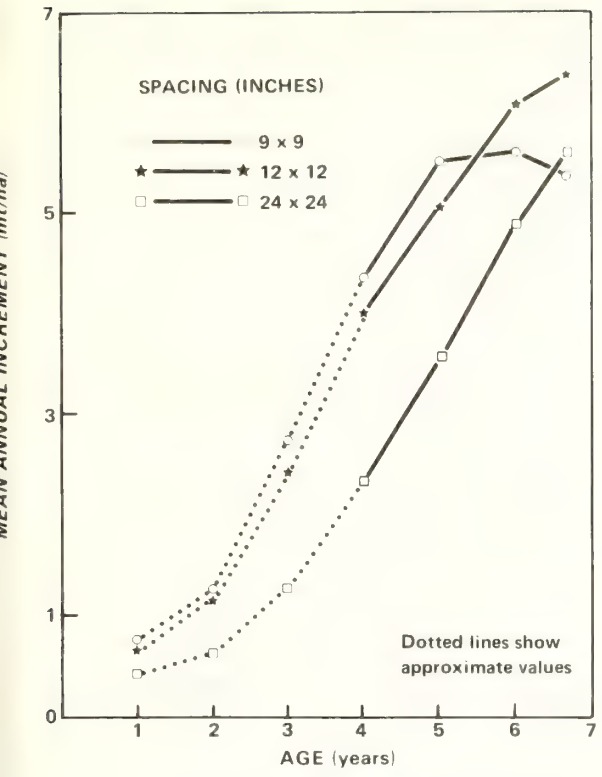

Figure 4.—*Mean annual increment of stems and branches in 1- to 7-year-old jack pine at three spacings.*

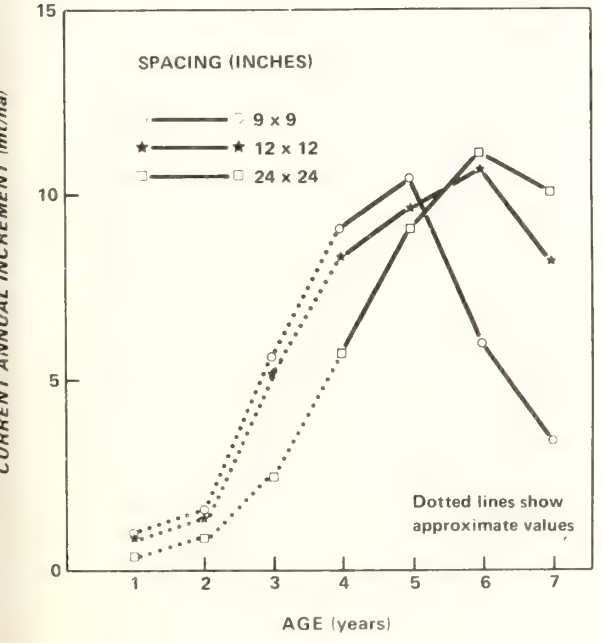

Figure 5.—*Current annual increment of stems and branches in 1- to 7-year-old jack pine at three spacings.*

Table 4.—*Mean annual increment and production*

(In mt/ha)

Age	Mean Annual Increment			Mean Annual Production		
	9 by 9	12 by 12	24 by 24	9 by 9	12 by 12	24 by 24
	BIOMASS					
4	7.0	6.4	4.1			
5	7.7	7.4	5.6	7.8	7.4	5.6
6	7.5	8.1	7.1	8.0	8.5	7.2
7	6.8	8.1	7.6	7.4	8.5	7.7
	STEM AND BRANCH BIOMASS					
4	4.3	4.0	2.4			
5	5.6	5.1	3.7	5.7	5.1	3.7
6	5.7	6.1	4.9	6.2	6.5	5.0
7	5.4	6.3	5.6	6.0	6.7	5.7

systems are not strictly comparable. However, in areas with adequate irrigation water and high demand for fiber (e.g., the Lake States), the SRIC system may allow the land owner to produce as much or more than can be produced in the southern and western parts of the United States. This point becomes even more pertinent when we consider the most productive species such as various *Populus* hybrids. Although the production in SRIC jack pine plantings was high, it was only half of what can be produced in SRIC *Populus* 'Tristis #1' plantings (Ek and Dawson 1976).

Stems

Through age 5, stem biomasses decreased with increased spacing (figs. 3 and 6). A reversal occurred at age 6, when the stem biomass of the 12- by 12-in. planting became the highest and remained so through age 7. Stem wood accounted for 78, 80, and 83 percent of the stem weight at the three spacings (table 6). The percentage in the 24- by 24-in. planting was significantly higher than in the 9- by 9-in. planting.

The m.a.i. of stem wood at age 7 was 3.1, 3.7, and 3.0 mt/ha/year as compared to 3.2, 3.4, and 2.3 mt/ha/year at age 6 in the 9- by 9-, 12- by 12-, and 24- by 24-in. plantings, respectively. It appears that the m.a.i. of stem wood in the 9- by 9-in. planting culminated at age 6 but it was steadily increasing in the two wider spacings. The sharp increase in the 24- by 24-in. planting suggests that the m.a.i. of stem wood (like that of other components) may eventually become the largest. The m.a.i. of stem wood in a 41- to 46-year-old jack pine stand in Quebec (Doucet *et al.* 1976) was 1.4 to 1.8 mt/ha/year and in an 11- to 20-year-old jack pine stand in Ontario it was 1.6 mt/ha/year (Hegyi 1972). The m.a.i. of stem wood of 4-year-old SRIC *Populus* 'Tristis # 1' was more than 10 mt/ha/year (Ek and Dawson 1976).

Table 5.—*Above-ground mean annual increment in selected forest plantations*

Species	Location	Age	M.a.i.	Reference
		Yrs.	*M³/ha*	
Pinus banksiana	N. Wisconsin	7	8.1	Present study, 12- by 12-in.
P. banksiana	N. Ontario	11-65	1.2-3.4	Hegyi 1972
P. banksiana	Quebec	41-46	1.4-2.5	Doucet *et al.* 1976
P. banksiana	N.E. New Brunswick	29-57	0.9-2.8	MacLean and Wein 1976
P. [illegible]	Japan	20-25	6.9	Ogasawara 1971
P. [illegible]	N. Carolina	8	4.0	Nemeth 1973
P. radiata	Australia	12	9.9	Forrest and Ovington 1970
P. [illegible]	N. Carolina	15	4.6	Swank and Schreuder 1973
P. [illegible]	United Kingdom	35	4.7	Ovington 1957
P. taeda	N. Carolina	12	9.0	Nemeth 1973
P. taeda	S. Carolina	14	6.2	Harms and Langdon 1976
P. virginiana	Virginia	17	4.8	Madgwick 1968
Pseudotsuga menziesii	Washington	36	5.7	Cole *et al.* 1967
Tsuga heterophylla	W. Oregon	26	7.4	Fujimori 1971

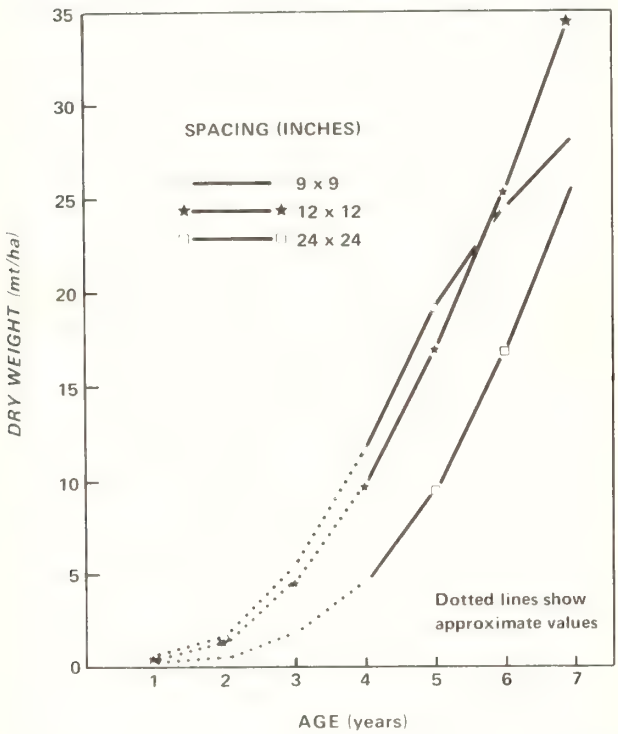

Figure 6.—*Stem biomass of 1- to 7-year-old jack pine at three spacings.*

Table 6.—*Biomass distribution among tree components in 7-year-old jack pine*

(In percent)

Spacing	Stem	Total tree			Stem		Branches	
		Branches	Needles	Other[1]	Wood	Bark	Wood	Bark
[illegible]	59[a]	19[a]	21[a]	1[a]	78[a]	22[a]	60[a]	40[a]
12 x 12	56[b]	22[b]	21[a]	1[a]	80[ab]	20[ab]	60[a]	40[a]
24 x 24	48[c]	26[c]	24[b]	1[a]	83[b]	17[b]	75[b]	25[b]

[1]Cones, buds, etc.

Values (in columns) followed by the same letter are not significantly different (p=0.05).

Branches

During the first 5 years, branch biomass was similar in all three spacings (fig. 7). A separation occurred at age 6 when the branch biomass increased with increasing spacing. The pattern was the same at age 7 and is likely to remain so in future years. At age 7, branches accounted for 19, 22, and 26 percent of the total biomass in the 9- by 9-, 12- by 12-, and 24- by 24-in. plantings, respectively (table 6). Dead branches made up about 30 percent of the total branch biomass in the 9- by 9-, and 24- by 24-in. plantings and about 43 percent in the 12- by 12-in. planting (table 7). Stem and branch wood, the two most important components for fiber production, averaged 27.4, 33.1, and 31.7 mt/ha at age 7 in the 9- by 9-, 12- by 12-, and 24- by 24-in. plantings, respectively (table 1). The stem and branch biomass from age 6 to age 7 increased by only 2.5 mt/ha in the 9- by 9-in. planting but increased by 6.1 and 9.4 mt/ha in the 12- by 12- and 24- by 24-in. plantings. The increase in the 24- by 24-in. planting is consistent with the general trend, which indicates that in future years the 24- by 24-in. planting will be the most advantageous for fiber production.

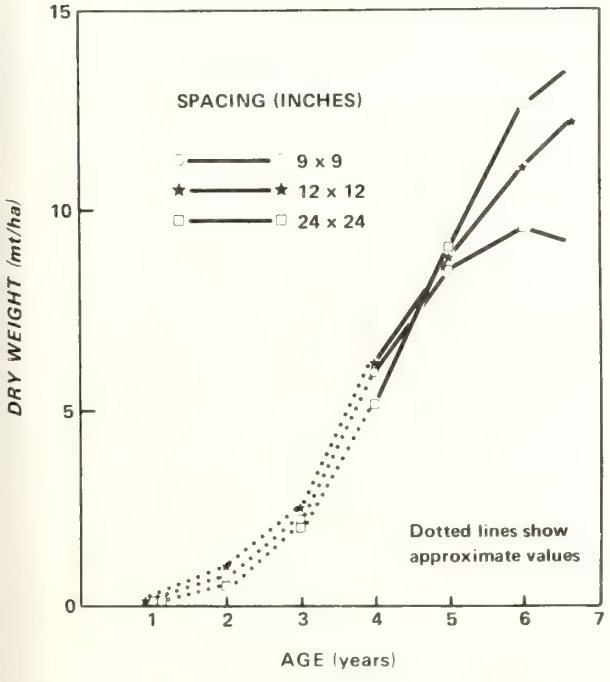

Figure 7.—*Branch biomass of 1- to 7-year-old jack pine at three spacings.*

Table 7.—*Branch and needle biomass distribution in 7-year-old jack pine*

(In percent)

Spacing	Branches			Needles		
	Current	Older	Dead	Current	Older	Dead
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12 x 12	17[a]	40[a]	[illegible]	41[a]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[1]Values followed by the same letter are not significantly different (p=0.05).

For comparison, the percentage of branch weight in the 41- to 46-year-old jack pine in Quebec decreased with density from about 19 percent in open stands to about 16 percent in dense stands (Doucet *et al.* 1976). In that study, branch percentages were affected by site quality—they reached 20 percent of the total biomass on medium sites and 15 percent on good sites. The implication for intensive culture is that by manipulating site quality—fertilizing and irrigating—the percentage of biomass in branches may be regulated.

Bark

Bark percentages of stems and branches decreased with increased spacing and age (table 8). Stem bark accounted for from 17 to 29 percent of the stem, and branch bark accounted for from 25 to 56 percent of the branch weight. Branch bark dry weights per hectare remained about the same at ages 6 and 7 and stem bark increased by more than 1 mt/ha in that 1 year (table 1) (Zavitkovski and Dawson 1977).

Table 8.—*Bark percentages on stems and branches*

(In percent)

Age	Stems			Branches		
	9 by 9	12 by 12	24 by 24	9 by 9	12 by 12	24 by 24
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	24[a]	[illegible]	n.a.	n.a.	n.a.	n.a.
6	19[a]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[1]Values with the same letter in each row are not significantly different (p=0.05).
n.a. Not available.

Stem bark percentages ranged from 9 to 11 percent in 41- to 46-year-old jack pine in Quebec (Doucet *et al.* 1976), about 10 percent in 11- to 65-year-old jack pine in northern Ontario (Hegyi 1972), and about 15 percent on stems of 50-year-old jack pine in Minnesota (Crow 1971). We found no information on jack pine branch bark in the literature.

Needles

Needle biomass increased rapidly during the first 4 to 6 years and then leveled off between 10 and 13 mt/ha (fig. 8). At age 7, living needles accounted for 88 to 97 percent of the total needle weight (table 7) and averaged from 9.6 to 11.4 mt/ha (table 9). Needle weight increased with spacing and also with the biomass of branches (figs. 7 and 8). The data indicate that the upper limit of living needle weight is less than 12 mt/ha. It appears unlikely that a higher needle biomass could develop in stands that allow less than 1 percent of the sunlight to reach the ground.

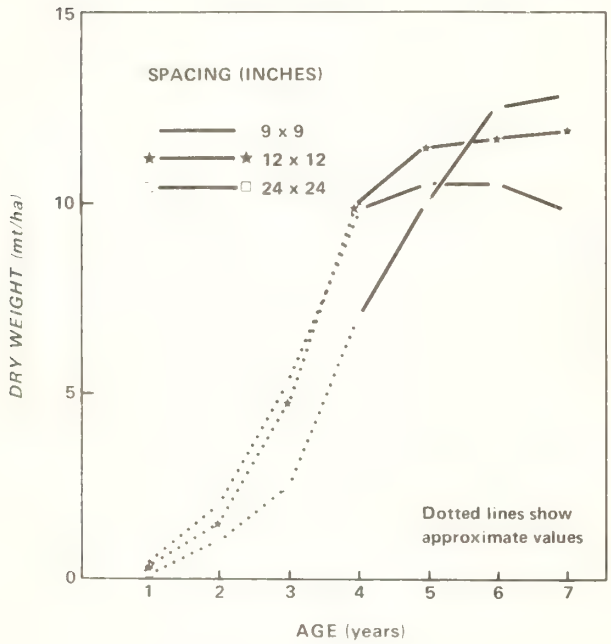

Figure 8.—*Needle biomass (including attached dead needles) in 1- to 7-year-old jack pine at three spacings.*

Table 9.—*Living needle biomass*

(In mt/he)

Age	All living needles			Current year's needles		
	9 by 9	12 by 12	24 by 24	9 by 9	12 by 12	24 by 24
4	8.4	8.0	7.1	n.a.[1]	n.a.	n.a.
5	9.4	10.2	9.0	n.a.	n.a.	n.a.
6	8.3	10.6	11.1	5.4	6.2	6.3
7	9.6	11.3	11.4	4.3	5.5	5.5

[1]Not available.

The percentage of total above-ground weight accounted for by needles increased with spacing and decreased with age (table 10). At age 7, needles made up about 21 percent of the total biomass in the two dense plantings and 24 percent in the 24- by 24-in. planting. Current year's needles accounted for 65, 58, and 57 percent of the living needles at age 6 and for 45, 49, and 48 percent at age 7 in plantings spaced at 9- by 9-, 12- by 12-, and 24- by 24-in., respectively. The steep decrease in the percentage of current needles in the 9- by 9-in. planting is evidence of increased competition, which was also responsible for a decrease in the c.a.i. and m.a.i. of stems and branches (figs. 4 and 5).

Needle biomasses of our stands were substantially higher than in jack pine stands tended in the traditional way. In 41- to 46-year-old jack pine in Quebec, needle biomass ranged from 3.45 to 7.7 mt/ha and needles accounted for from 4 to percent of the above-ground biomass (Doucet *et al.* 1976). Needles made up about 9 percent of the

Table 10.—*Needles as percentages of total biomass*

(In percent)

Age	Spacings (inches)		
	9 by 9	12 by 12	24 by 24
4	37	38	45
5	30	32	44
6	23	24	29
7	21	21	24

above-ground biomass in 11- to 65-year-old jack pine in northern Ontario (Hegyi 1972). Biomass regressions in that study indicate that the percentage was higher for younger and smaller trees (about 18 percent for trees 3.0 cm in d.b.h.) than for older and larger trees (about 4 percent for trees 30 cm in d.b.h.). In 50-year-old jack pine in Minnesota (Crow 1971), needles made up about 8 percent of the above-ground biomass and appeared to increase as the tree size increased.

Needle dry weights in the Quebec stands were substantially higher on the medium than on the good sites (Doucet *et al.* 1976). This contradicted trends reported by others who found either a strong positive relation between site quality and needle biomass (Burger 1953, Hutnik 1964, Satoo 1967a), a slight positive relation (Satoo 1967b), or no relation (Moller 1945). This question is important for the concept of intensive culture because fertilization and irrigation increase site quality and foliage biomasses. Doucet *et al.* suggested that the generally longer crowns in stands on the medium sites were probably responsible for the higher foliage biomasses on those sites. More importantly, however, they observed that the total net annual weight increment for the previous 5 years was higher on the medium than on the good site. Although that is encouraging for the intensive culture system, it doesn't explain the sudden reversal in productivity during the last 5 years.

We found a positive relation between living needle biomass and c.a.p. of stems and branches for ages 4, 5, and 6 (fig. 9) but the 7th year data fell below this block of data. Perhaps the inadequate irrigation in 1976 reduced stem and branch c.a.p. below that expected from the regression. If this explanation is correct, then not only the production of stems and branches but also that of current year's foliage would be affected and a relation between current year's foliage biomass and the c.a.p. of stems and branches would show no deviation from linearity, even for the droughty 1976. Unfortunately, the information on current year's foliage biomass is only available for the 1975 and 1976 season (table 9). However, the relation was good, the current year's foliage biomass accounted for 93 percent of the variation in the c.a.p. of stems and branches, and the data showed no separation (fig. 10).

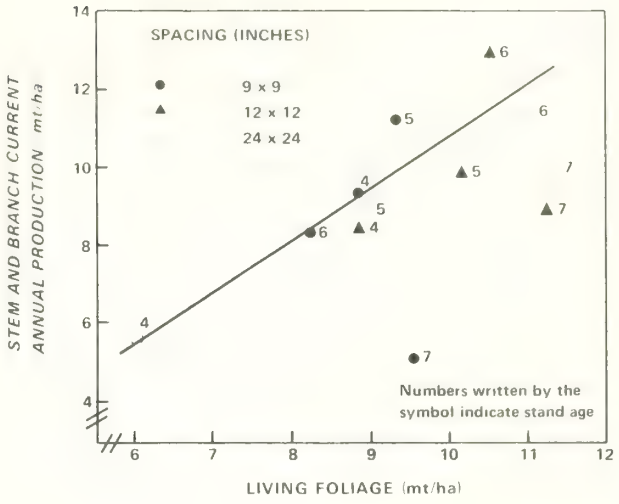
SPACING (INCHES)
9 x 9
12 x 12
24 x 24
Numbers written by the symbol indicate stand age
STEM AND BRANCH CURRENT ANNUAL PRODUCTION mt/ha
LIVING FOLIAGE (mt/ha)

Figure 9.—*Relation between living needle biomass and current annual production of stems and branches in 4- to 7-year-old jack pine at three spacings. Regression for the 4- to 6-year-old stands:* $Y = -2.32 + 1.29x$; ($R^2 = 0.81$; $S_{y.x} = 0.98$).

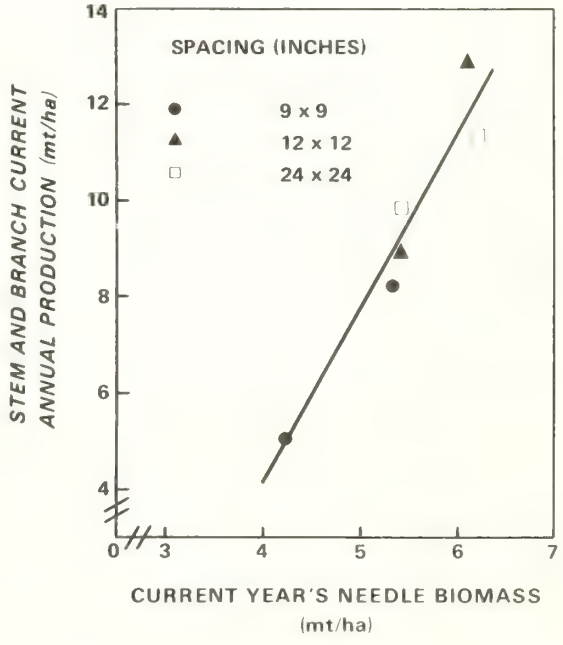

Figure 10.—*Relation between current year's foliage and current annual production of stems and branches in 6- and 7-year-old jack pine at three spacings. Regression* $Y = -10.6 + 3.62x$; ($R^2 = 0.93$; $S_{y.x} = 0.81$).

APPLICATION OF SRIC SYSTEM TO JACK PINE

Results of our studies indicate how the system could be applied, what could be improved to further increase the production, and what yields can be achieved under good growth conditions. These preliminary results were obtained in small sample plots and will have to be confirmed in larger experimental plantations. In spite of the uncertainties about the exact production, the findings indicate that the SRIC system will strikingly increase biomass production in comparison to that achieved in traditional silvicultural systems.

Plantation Establishment

The use of plastic tube containers, at least of the type used in our studies, should be avoided. Height growth of our seedlings was drastically reduced during the first 2 years compared to other seedlings. Other types of containers that may further speed up growth and reduce losses are being tested.

Effects on Irrigation

Although determining an optimum level of soil nutrients and soil moisture were not objectives of our studies, the reduced irrigation during the 1976 droughty growing season showed how important soil moisture is for forest production. We have not determined the optimum irrigation amount or schedule, but studies are in progress to evaluate effects of both irrigation and nutrients on growth of forest plantations (Hansen 1976).

Spacing and Rotation

One of the objectives of our study was to find the optimum combination of spacing and rotation with respect to biomass production. The optimum rotation depends on spacing and, in general, is shorter for dense plantings. In this study, the optimum biological rotation for the 9- by 9-in. planting would be 6 years because it was then that the m.a.p. of stems and branches peaked (table 4). For the 12- by 12-in. planting the optimum rotation would be 7 years because it was then that the m.a.p. peaked. The optimum rotation in the 24- by 24-in. planting was not reached during the 7 years but the shape of the curve for the m.a.p. of stems and branches indicates that it will be reached in about 2 years and may be higher than in either of the denser plantings. Similar relations can be seen in Ek and Dawson's (1976) data for intensively-cultured *Populus* 'Tristis #1'.

Biomass Allocation and Wood Quality

The quality of the wood is beyond the scope of this study. However, biomass distribution among tree components was affected by spacing and that may affect the suitability of the material for various industrial purposes. Percentages of both branches and needles increased (and would tend to reduce the quality) and percentages of stem and branch bark decreased (and would tend to increase the quality of material) with increasing spacing. Moreover, the average size and number of harvested trees will be strongly affected by spacing and may require different types of harvesting equipment.

Jack pine was included in our intensive culture studies because it is widely used by the pulp and paper industry—mature jack pine fibers are long and suitable for industrial purposes. However, Crist *et al.* (1977) have shown that the fiber quality of juvenile jack pine is lower than that of mature trees and does not appreciably differ from that of *Populus* 'Tristis #1' whose m.a.i. of stems and branches under SRIC systems is at least two times higher than the m.a.i. of jack pine.

Role of Canopies in Production

The positive and significant relation between living needle biomass and the c.a.p. of stems and branches illustrates the importance of forest canopies for maximizing forest production. The quantity of foliage can be manipulated by fertilization and irrigation. Still unknown is the optimum foliage biomass, which is as important in forest production as the optimum leaf area index is in agronomy. The importance of optimizing foliage biomass is illustrated by the following example for red alder (Zavitkovski *et al.* 1974): maximum annual production was reached in stands with a leaf biomass of about 5.5 mt/ha—at higher foliage biomasses, production of stems and branches was reduced from about 11 mt/ha/year to about 10 mt/ha/year. It was not possible to estimate the optimum leaf biomass i

our jack pine plantings and, it would be unwarranted to attach any significance to the lower production observed in the 24- by 24-in. planting that had the maximum foliage biomass of 11.4 mt/ha at age 6 (fig. 9).

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Forest Fires in Pennsylvania

Donald A. Haines
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FOREST FIRES IN PENNSYLVANIA

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A special fire-weather forecast on the afternoon of April 15, 1976, stated, "High forest fire danger over Pennsylvania and New Jersey. There has been little significant precipitation for some time over either State. Very low humidities of the past several days intensified this situation with resultant high fire danger. Since very little significant precipitation is expected for the next several days, the danger is not expected to lessen."

During the early afternoon of April 19, a weather observer near Haneyville reported northwesterly winds of 14 miles per hour, relative humidity of 24 percent, and fine fuel moisture of 3 percent. At 1:25 p.m. a primary electric line on the east side of highway PA-44 near Haneyville broke and ignited the fine fuels along the highway. Another fire, Wallis Run, started from burning debris on the same District 5 minutes before the electric line fell. Key personnel from the District Forester's office were enroute to this fire when they received the report from Haneyville.

The Haneyville fire spread rapidly, moving into oak stands where the oak leaf roller, oak leaf tier, and two-lined chestnut borer had caused extensive mortality. By 2:55 p.m. spotting was observed a quarter of a mile ahead of the main fire. The fire burned 3,330 acres before it was extinguished on April 21 and required the suppression efforts of 18 Forest Fire Wardens, 392 crew members, and 26 State Forest and Park employees. During the same period the Wallis Run fire burned 280 acres and required 166 suppression personnel plus men and equipment from 5 volunteer fire companies.

It is an unusual year when there are not at least 1,000 wildfires in Pennsylvania with an occasional Haneyville fire not uncommon. This fire load requires responsive fire management programs which are developed, in part, by evaluating fire and weather records. The following is such an evaluation, including an attempt to determine how the information might fit into an overall approach to the problem of protecting the forest from wildlife. Although conventional fire statistics are included, this investigation is mainly concerned with other types of analysis.

BASIC FIRE STATISTICS

A tabulation of Pennsylvania's fire activity is published annually by the State (Division of Forest Fire Protection 1977) and by the USDA Forest Service (1977). Summary statistics used in this paper were taken from these sources as well as from 1936-1974 punched-card data and 1914-1974 Pennsylvania office tabulations. The long-term data include number of fires, total acres burned, and cost of extinction. Extinction cost is what is actually spent to fight fires, not fixed, administrative costs. The punched-card data include fire cause, man-hours to control, damages, and individual fire size. Although these data make many statistical comparisons possible, we have

included only those that provide an interpretive base for management planning.

The long-term data show some interesting features. Number of fires is affected not only by weather and fuel conditions but also by prevention efforts (fig.la). The annual average number of fires decreased more than 50 percent from 1914 to 1974. This appears to reflect the modernization of the State fire forces which occurred in the mid-1940's and an increased emphasis on prevention.

Management factors are also evident in the long-term statistics of acres burned (fig. 1b) because the number of acres burned decreased expotentially. It was not unusual for hundreds of thousands of acres to burn during the early years, but only once after the mid-1940's did the acreage burned exceed 50,000 acres. Increased efficiency in suppression efforts is one of the reasons for this trend as evidenced by the steadily decreasing annual number of large fires (those greater than 10 acres) (fig. 1c).

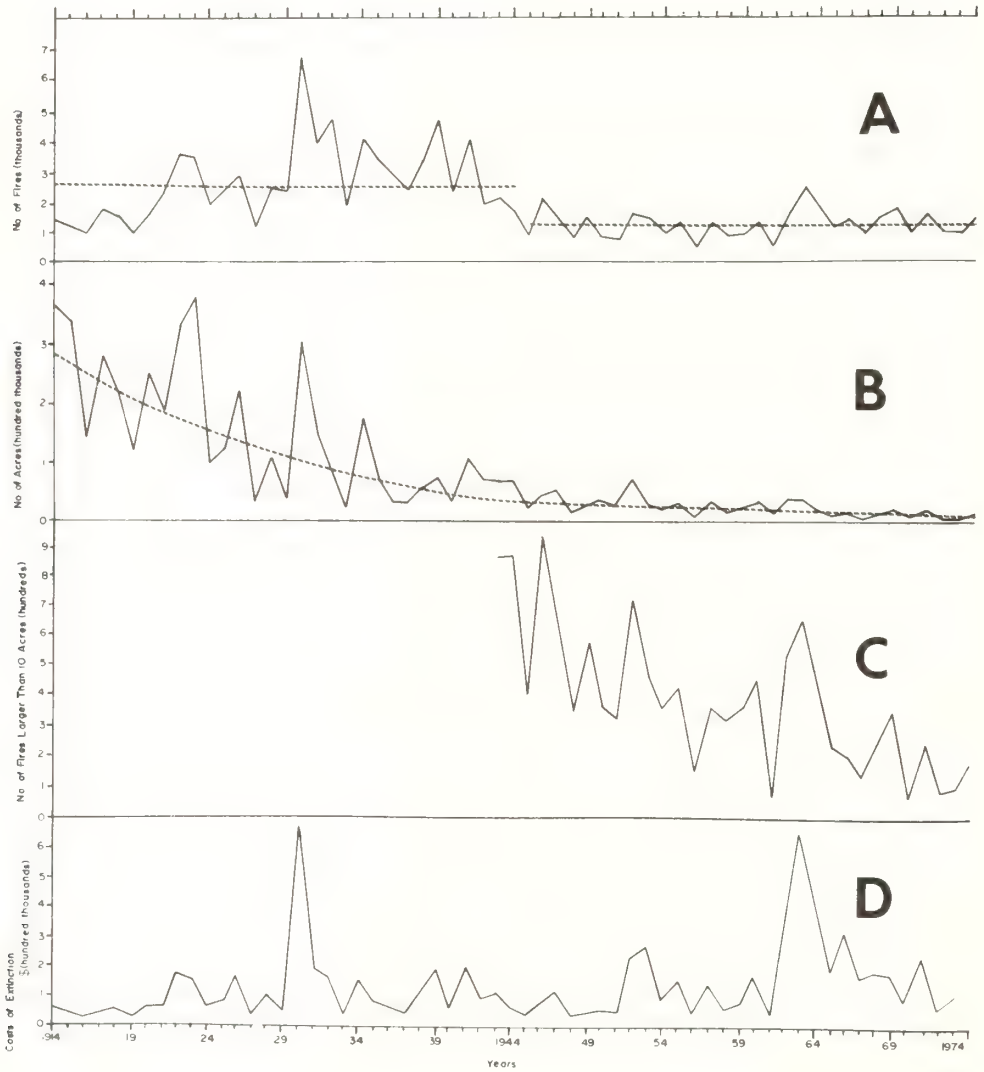


Figure 1.—*Four measures of fire activity:* (*A*) *Number of fires from 1914 to 1974. Dashed lines show the average for 1914 to 1944 and 1945 to 1974.* (*B*) *Number of acres burned from 1914 to 1974. The dashed line shows the trend with time.* (*C*) *Number of fires larger than 10 acres, 1942 to 1974.* (D) *Cost of extinction excluding fixed, administrative costs.*

The State's spatial distribution of fires shows he heaviest concentration in the forested east and outh-central (fig. 2). Counties of major concern clude: Franklin, Lackawanna, Luzerne, North- mberland, and Schuylkill. Except for Franklin, hese are coal-bearing areas and have a long istory of man-caused fires.

SEASONAL DISTRIBUTION OF FIRE DURING NORMAL, DROUGHT, AND WET YEARS

Some figures in this section are presented as ercents of peak class. For the "peak class" ethod a value of 100 percent is assigned to the eek of the year that had the most fires and then this value is used to calculate percentile values for the remaining weeks. This method normalizes the data so fire activity between different areas can be statistically compared.

Pennsylvania has been partitioned into climatic divisions that correspond to fire-weather forecast zones (fig. 2). Discussion in this and following sections concentrates on three climatic divisions that has high fire-incidence—the Pocono Mountains, Middle Susquehanna, and South Central Mountains.

The Normal Year

The fire distribution pattern of the Pocono Mountains division is typical for Pennsylvania and

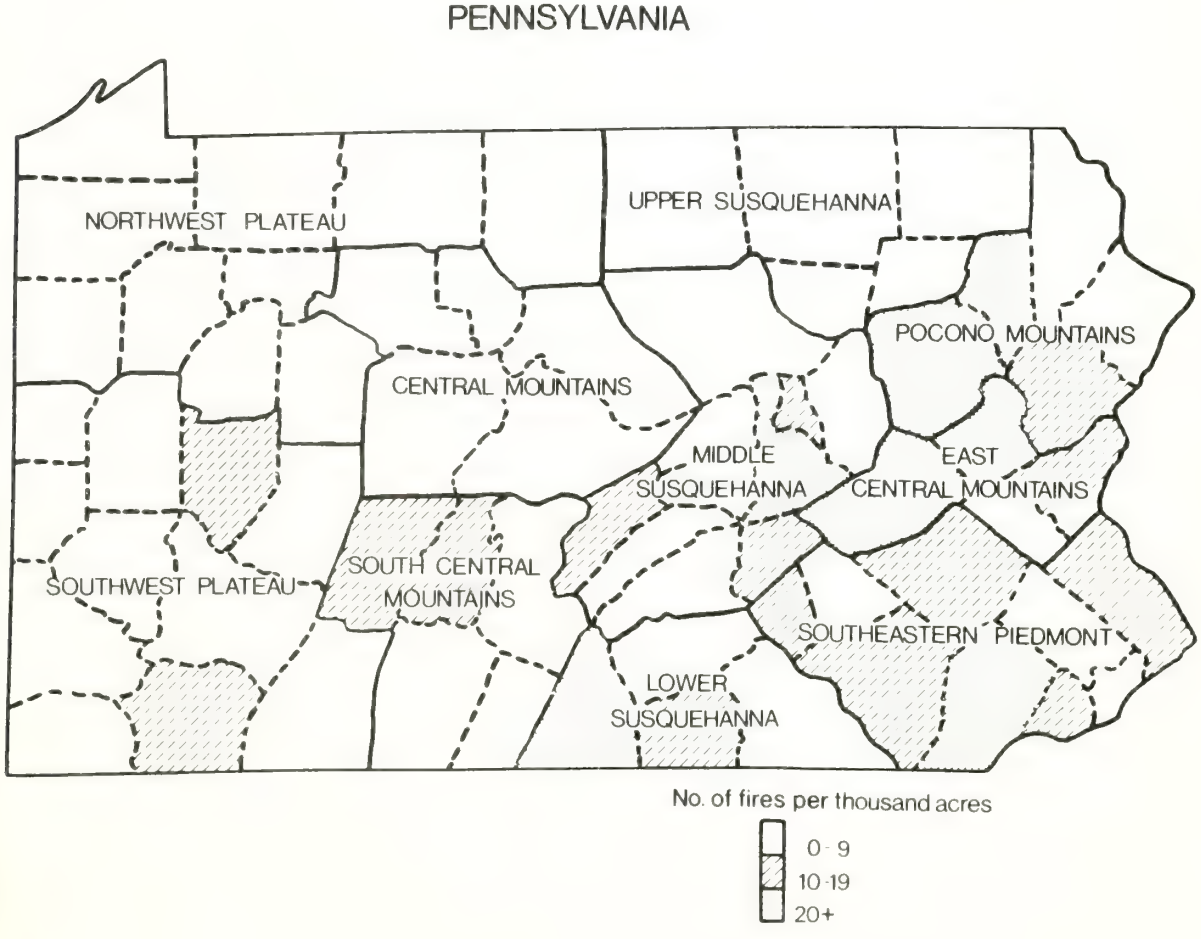


Figure 2.—*Average annual number of fires per thousand acres by county, 1970 to 1974. Also shows climatic divisions, which in most cases correspond with fire-weather forecasting zones.*

for much of the northeastern United States (fig. 3). Spring fire activity peaks in late April and autumn fire activity peaks in late October. If we define the beginning of the fire season as the week when fire numbers reach 10 percent of the greatest activity (Haines and Johnson 1975), then the spring season begins the third week in March and ends in mid-June; the autumn season begins in early October and ends in late November.

Other Pennsylvania divisions closely agreed with this same spring fire activity pattern, but differed somewhat for the autumn season. The Pocono Mountains division experienced fire numbers of 25 percent of the worst week of the spring season, but the Middle Susquehanna had an autumn week of more than 40 percent of peak week and the South Central Mountains had an autumn week that averaged 65 percent of peak week.

The peaks and valleys in fire occurrence ar highly dependent on seasonal changes in weather fuels, vegetation, and human activity. Durin April, the most severe fire month, incoming sola radiation is almost the same as it is durin August. But hardwood forests are devoid o foliage in the spring so more solor radiatio reaches litter and slash. Also in the spring ther are more litter fuels due in part to slow sheddin of dead foliage by some oaks. Spring is the time o year when deep low-pressure areas develop ove the United States and produce extended periods o strong winds in Pennsylvania. Low humiditie coupled with these strong winds make this seaso optimum for fuel drying.

In May the hardwood forest produces a leaf canopy that greatly reduces solar radiation at th forest floor. The humidity increases and wind speed decreases. The change is especiall

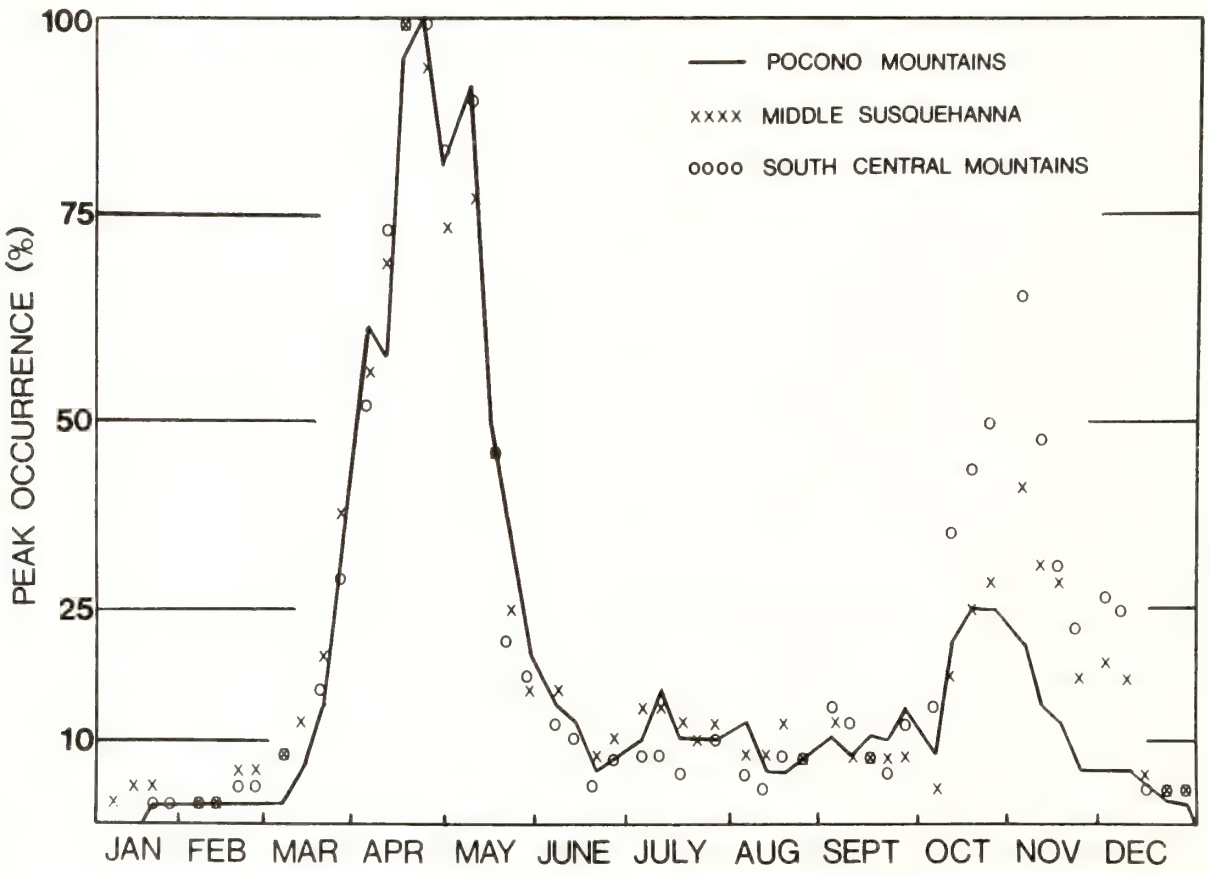


Figure 3.—*Number of fires during the average year for three climatic divisions, 1936 to 1974. Data are presented as a percent of peak occurrence. The week with the most fires is assigned a value of 100 percent with all other weeks assigned a percentage value relative to that week.*

parent under the forest canopy. In summer, er fuels decay rapidly and are at the annual nimum. During the summer the lower vegeta- n is also in full growth. Both the tree canopy d the lower vegetation create conditions that duce the probabilities of fire ignition and read.

As autumn approaches, the lower green getation begins to mature. Grasses and other rbaceous vegetation cure rapidly and in tober and November a large portion of the nopy of hardwood leaves fall and become part of e surface fuels. The days are shorter and mperatures lower; therefore, burning periods e normally short and infrequent. During winter, rface leaves often dry to low moisture content, t the duff generally retains moisture so the few es that start do little damage.

Drought and Wet Years

Meteorological drought is defined as a pro- ged and abnormal moisture deficiency, and the erity of a drought is a function of moisture mand as well as moisture supply (Palmer 1964). ought depends upon the local climate; for mple, normal meteorological conditions in w Mexico would be regarded as drought- ducing in Pennsylvania. Also, time must be sidered as a drought factor because it usually es many weeks or months for serious ditions to develop.

Forest fire potential can be gauged with the mer (Drought) Index. This Index evaluates the gree of drought on a numerical scale and can be related with such things as general crop ditions, water supplies in streams and lakes, d forest fire danger.

The Palmer Index is, by design, a slow response tem most applicable to conditions in subsur- e soil. It does not reflect the fire situation in ing when critical surface conditions are nging rapidly and subsoil conditions usually a minor role in fire danger and fire behavior. s Index is applicable during summer and early umn when deep burning, large fires are a ificant threat in the northeastern United es (Haines *et al.* 1976).

During the period 1929 to 1963, Fieldhouse and Palmer (1965) found that within the climatic divisions of the State (fig. 2) the number of droughts varied from 29 in the Pocono Mountains to 42 in the South Central Mountains. Statewide, during these same years, the percent of months with indicated drought severity was as follows: Incipient, 11 percent; Mild, 18 percent; Moderate, 11 percent; Severe, 6 percent; and Extreme, 3 percent. This means that, on the average, moisture stress is evident almost 50 percent of the time, although most of these stress periods are not serious.

A drought is often geographically selective. For instance, the extreme drought of the mid-1960's did not affect all divisions of the State to the same extent. Drought was of concern in much of the forested region of the State, but it was a near disaster in the extreme east. The Pocono Mountains division was in some stage of drought from mid-1961 to mid-1969 (fig. 4) and did not enter a substantial wet period until the summer of 1971. This situation is reflected in the number of wildfires—301 wildfires in 1963 and 387 in 1964, the only years with more than 300 fires from the mid-1940's to present in that division.

An interesting feature of these drought periods involves the sudden taxing effect on the State's fire management organization. Cost of extinction, for example, increases dramatically (fig. 1d). The two extreme drought periods of the early 1930's and the mid-1960's stand out as unusually costly periods in relation to the rest of the record.

The month-to-month importance of drought to wildfires can be determined by statistically analyzing two measures of fire control. The first analysis shows drought's effect on the occurrence of fire as measured by fire-days[1] (fig. 5). Drought's impact on fire occurrence is strongly evident from May through September, therefore, continuous prevention efforts should be in effect during this period when drought dominates. The second analysis shows influence of drought on difficulty-of-control as measured by cost-to-suppress (fig. 6). Values are highest from April through October so droughts effects are most important during these months.

[1] *A fire-day is defined as a day having at least one reported fire in the protected area.*

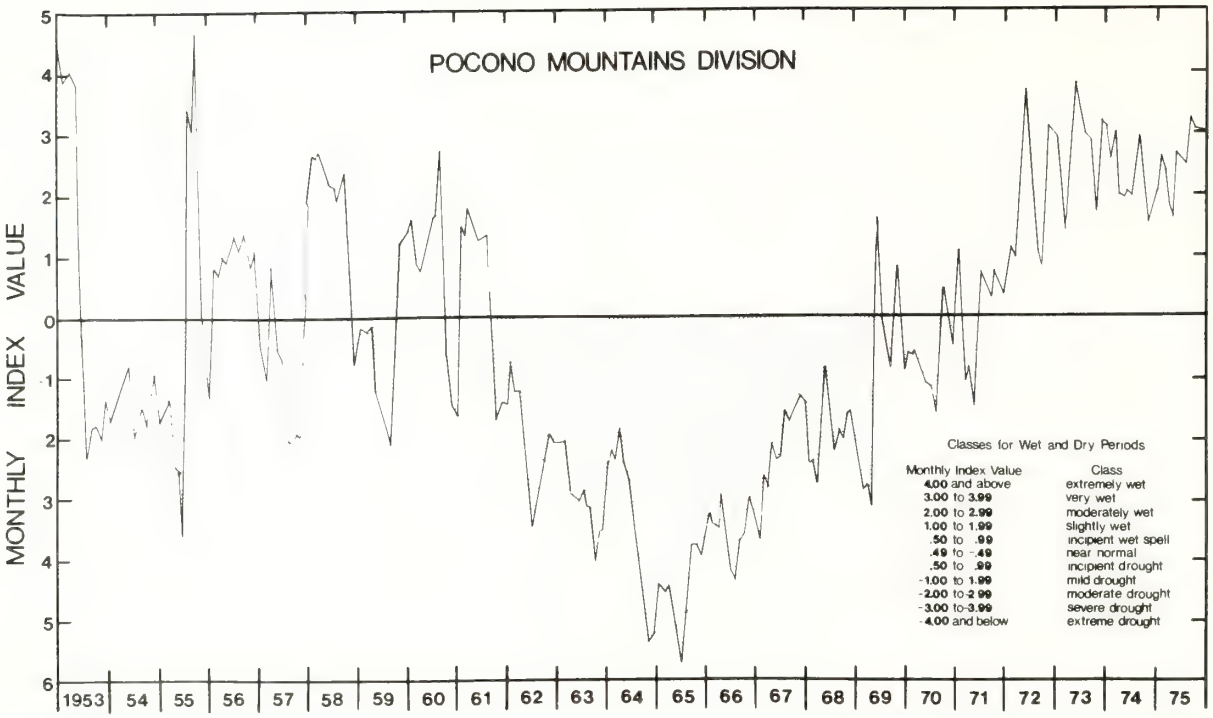


Figure 4.—*Monthly values of the Palmer (Drought) Index for the Pocono Mountains division, 1953 to 1975.*

Seasonal wet or dry periods will drastically change the yearly distribution of wildfires (fig. 7). During years with a dry spring followed by a wet fall there is a strong spring fire season and little fire activity in summer and autumn. But during years with a wet spring followed by a dry autumn the peak fire activity week will often occur in November and there may be heavy fire activity by early September. The wet early season produces abundant lower vegetation. In its lush green stage it acts as a strong heat sink and fire barrier. The dry late season changes this barrier into a fire carrier because of the large increase in dead fine fuels.

During years with a dry spring and fall the most distinct feature in the seasonal profile based on peak occurrence was increased fire activity during the summer as a percentage of peak spring class. During years with a wet spring and fall, there was no summer activity.

FIRE CAUSE

Weather, fuel, and vegetation stage are facto in fire danger but so are the attitudes and habits people. As people's attitudes and habits chang so does the distribution of fires in the vario cause categories. Campfires were the major cau of wildfire through the 1950's, however, part this dominance may be due to reporting metho (table 1)—other factors such as smoking, which now a separate classification, were former included under campfires. Nevertheless, th decline of campfires as the predominant cause wildfire is impressive. In the 1930's, 64 percent fires fell into the campfire category; tod campfires account for only 3 percent of total. Th decrease in these fires is mainly due to fi prevention efforts and changes in campin recreation activity. In the 1930's camping oft consisted of establishing an individual site to th best of the recreationist's abilities. This usual

cluded primitive cooking-fire arrangements. oday's modern campgrounds and fire sites have duced this hazard (Creelman 1974).

Three other cause classifications—debris, rail-ad, and incendiary—also show interesting nds. Debris fires as a percentage of total fires creased slowly from the beginning of records rough the 1950's, declined sharply in the early 60's, and then rose rapidly again in the late 60's (fig. 8). This upward trend may have been e to the clean-up activity of people who bought second homes and cottages. Since 1971, debris fires have again begun to decrease. This decrease seems to be due to : (1) trash pickup as a regular service of municipalities, (2) local ordinances regulating trash burning because of air pollution regulations, and (3) intensification of the "problem township program" (Creelman 1974). The "problem township program" was begun to reduce the number of fires in townships that had 10 or more fires per year for 5 or more years. A plan was designed for each township to reduce its number of fires. The plans differed depending on the specific causes of fires that were occurring.

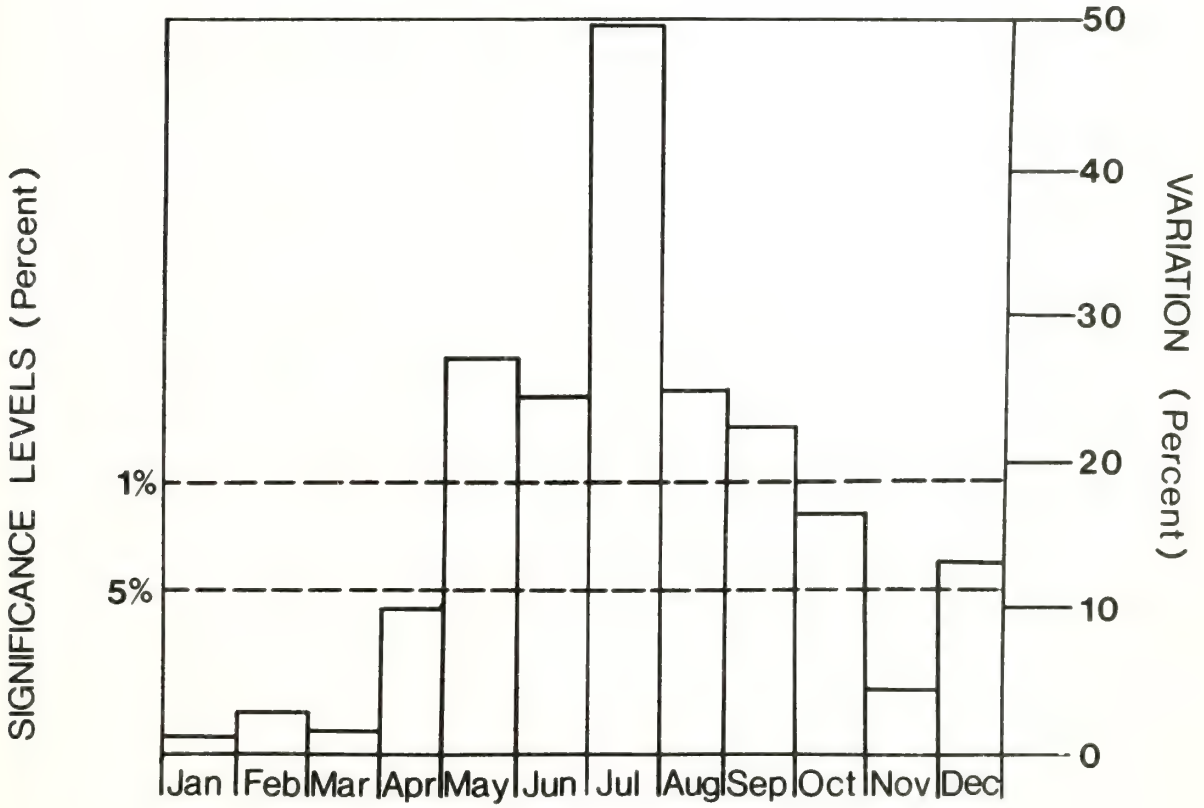


Figure 5.—*Percentage of the variation of fire days associated with the Palmer (Drought) Index and related significance levels, Pocono Mountains division. Each set of monthly data, 1943 to 1974, was computed as a coefficient of determination* (r^2), *i.e., a square of the correlation coefficient. The simple correlation coefficient is a measure of the degree of linear association between two variables, in this case fire days and drought index number.*

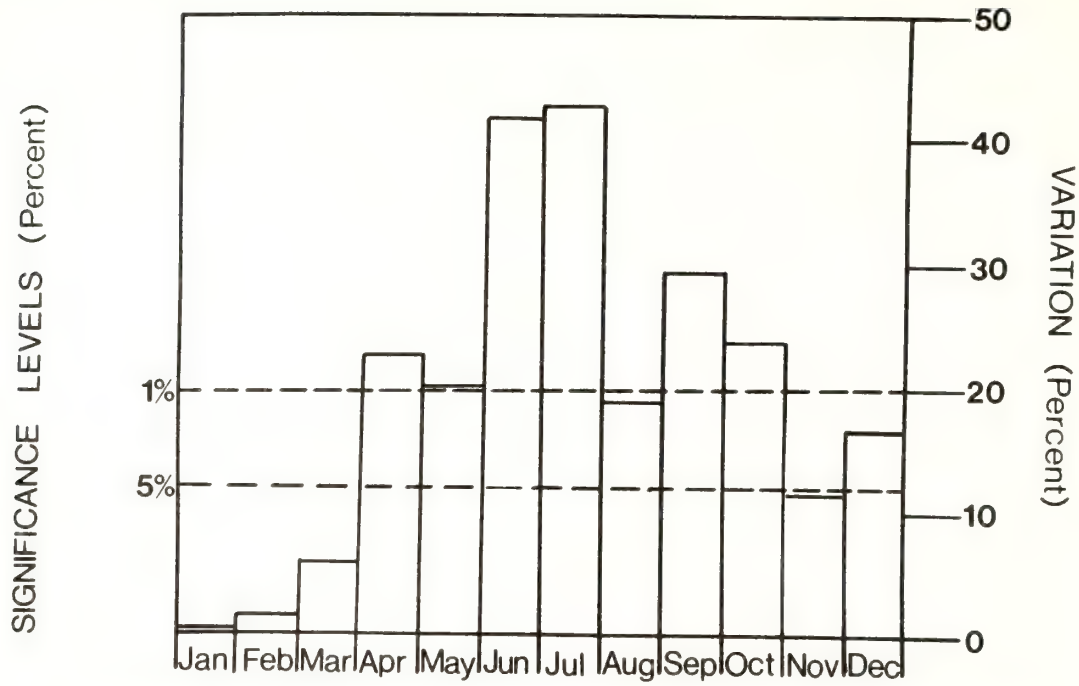


Figure 6.—*Percentage of the variation of cost-to-suppress associated with the Palmer (Drought) Index and related significance levels, Pocono Mountains division. Data were computed by the same method explained in figure 5.*

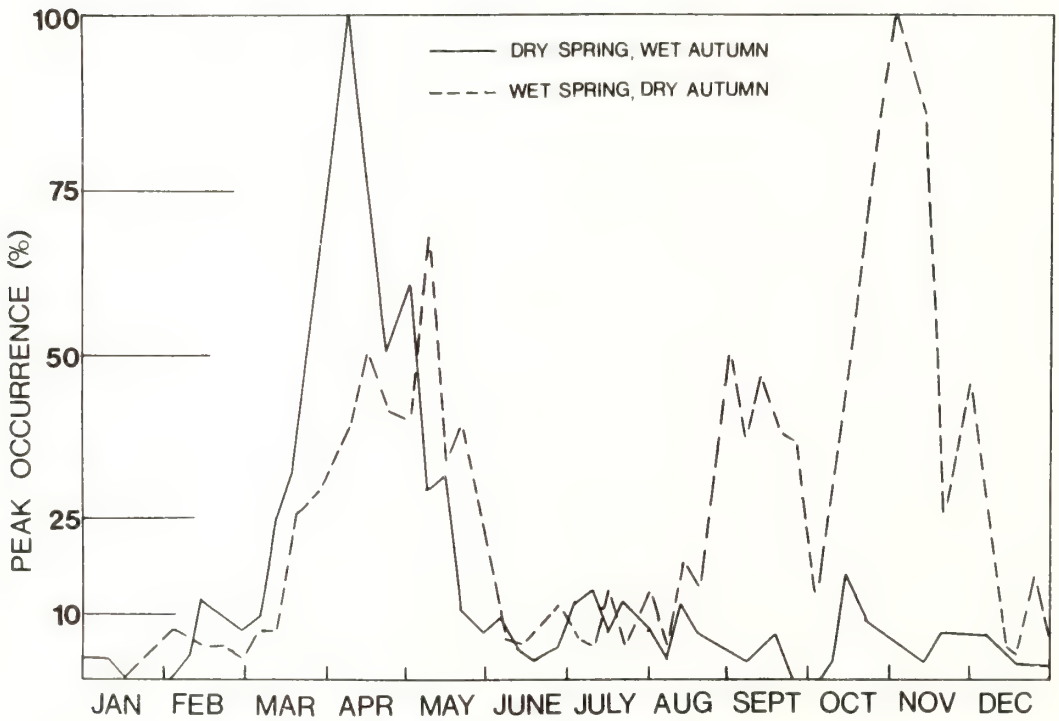


Figure 7.—*Number-of-fires as a percentage of peak occurrence in the middle Susquehanna division during years with:* (a) *dry spring and wet autumn,* (b) *wet spring and dry autumn. Wet-dry division was set at -0.5 on the Palmer Index.*

Table 1.—*Fires by cause category by decade*

(In percent)

Cause	1936-1939	1940-1949	1950-1959	1960-1969	1970-1974
Campfire	64	51	45	13	3
Railroad	12	19	17	15	16
Debris	7	10	16	15	21
Incendiary	6	7	10	23	29
Other	11	13	12	34	17
Equipment					3
Smoking					11

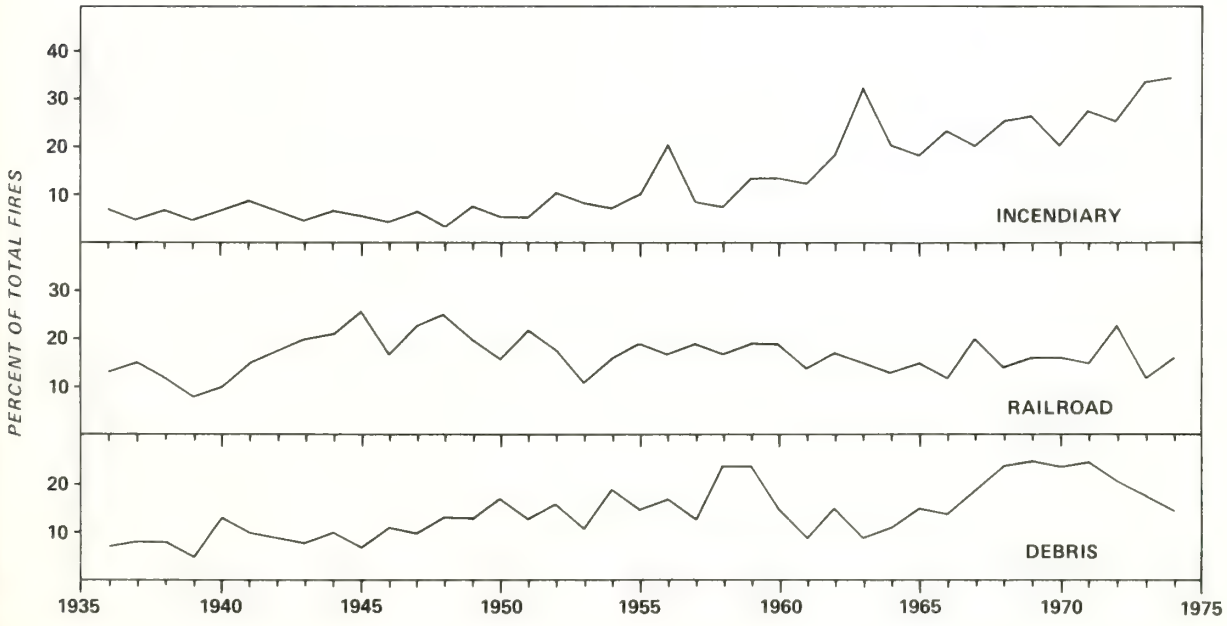


Figure 8.—*Annual percentages of total fires in three cause categories, 1936 to 1974.*

"The railroad fire problem in Pennsylvania is very similar to the problem in other heavily forested States in the Northeast. It is a problem that in spite of some intensive work on the part of fire protection personnel over...many years...does not seem to improve."[2] This 1960's statement is somewhat pessimistic. During the introduction of the diesel locomotive in the late 1940's the State averaged almost 300 railroad fires per year. The yearly average was reduced to 180 fires during the 1950's. The drought of the 1960's plus locomotive deterioration brought railroad fires to 230 fires per year, however this average fell to 134 during the early 1970's. Railroad fires, as a percentage of total fires, peaked in 1945 and have been slowly declining ever since, although railroad fires have had much the same impact on the *total* State fire picture from the early 1950's to present (fig. 8). Twenty-eight railroad companies operate in and through Pennsylvania on 9,357 miles of rights-of-way. But prevention specialist believe that something can be done to prevent railroad fires because many railroads operate without causing forest fires and also because these fires are definitely predictable.

Incendiary fires were an incidental percentage of total fires until the early 1950's (fig. 8). Since then they have become the most important single cause of fires. This phenomenal rise is not unique to Pennsylvania. Incendiarism is now the largest source of man-caused fires over much of the nation. It is also very difficult to prevent incendiary fires. However, the Pennsylvania Division of Forest Fires Protection issued an action plan on incendiarism based on the belief that *all* man-caused fires are preventable.[3]

The monthly Statewide breakdown of almost 6,000 wildfires by cause during the early 1970's shows some interesting features (table 2).

[2]*Division of Forest Fire Protection. 1968. The railroad forest fire problem in Pennsylvania. Unpublished manuscript on file at the Bureau of Forestry, Department of Environmental Resources, Harrisburg, Pennsylvania.*

[3]*Division of Forest Fire Protection. 1976. A guide to incendiary problem analysis. Unpublished manuscript on file at the Bureau of Forestry, Department of Enviromental Resources, Harrisburg, Pennsylvania.*

Twenty-nine percent of total State fires w attributed to incendiarism, but this percenta doesn't hold through all months of the ye Incendiary fire numbers are near the ann average percent in the spring, but they account 40 plus percent of total fires in the fall.

Debris fires are largely a spring phenome specifically during the month of April, and probably a result of spring cleanup. To counte this upsurge, prevention efforts in this cause a should be emphasized each spring.

Railroads are the leading cause of fires in off-season months, June and August, and a major problem during late winter and spring. Because railroads are in fixed locat the fires begun by trains are in specific locat This factor leads to some interesting effects example, a spring fire along a railroad righ way often burns all available fuels, neg autumn fires. However, even with available f autumn railroads fires are usually inconseque unless a drought conditions has placed the l vegetation in a state of high hazard.

FIRE ACTIVITY BY DAY-OF-WE

Many managers believe that because of cert social patterns, day-of-week is an import consideration in fire-control planning. Weeker holidays, and other special occasions all prod broad similarities in human activity, which may related to variations in fire occurrence. Haine *al.* (1973) reported that forest use is one of most critical influences on day-of-week numbers. For example, they showed that he recreational activity increased the number weekend fires on the Clark National For although there were no such increases on nea State forests where other forest uses dominat Certain cause categories display strong pre ence for specific days of the week (fig. Campfires are a special risk on Saturdays as fires from children, debris burning, incendiari and tobacco smoking. Campfires, children fi and incendiarism are also high on Sunda Equipment and railroad fires show little day week preference.

Table 2.—*Wildfires by cause as a percent of monthly total for Pennsylvania, 1970 to 1974*

(In percent)

Cause	Jan	Feb	Mar	Apr	May	Ju	Jy	Aug	Sept	Oct	Nov	Dec	Annual total
Incendiary	28	33	31	28	26	30	23	9	40	40	43	25	29
Debris	26	19	22	26	16	7	16	17	9	9	9	16	21
Railroad	19	24	21	15	23	34	8	30	17	8	4	2	16
Children	0	18	9	12	13	12	16	12	12	6	5	3	11
Smoking	6	1	7	10	12	8	25	10	8	15	18	23	11
Other	21	5	10	9	10	9	12	22	14	22	21	31	12
Monthly percentage of annual	1	1	12	51	16	2	1	2	1	6	6	1	100

Percentage of fires on Tuesdays, Wednesdays, d Thursdays are well below the expected and on turdays and Sundays are well above. Weekends ovide increased leisure time and, therefore, ng increased fire activity in recreation (camp- es and smoking fires), property cleanup (debris es), and general mischief (children and in- ndiary fires). Railroads, on the other hand, erate routinely through the week.

To see if there were seasonal differences in the mber of fires by day-of-week, we separated the ta into spring and autumn categories. In the ring the pattern was similar to the total mmary (fig. 9) except that railroad fires were nificant on Fridays; campfires, debris, and ldren fires were high on Saturdays; and oking, children, incendiary, and campfires re high on Sunday. Autumn fires showed little y-of-week variation for any cause category, hough, in total, Saturdays showed a signifi- ntly higher incidence of fire.

We also examined large fire (more than 10 res) data by cause for day-of-week but found no nificant patterns. Large fires are apparently termined by random weather events and the ccess of initial attack.

A further analysis of fires by day-of-week by ographic area showed strongest activity cen- ed in the Lower Susquehanna and the South ntral Mountains on Saturdays. Less active as of high Saturday fire activity in the northern f of the Northwest Plateau as well as other ttered areas also appeared.

THE MULTIPLE-FIRE DAY

When fires are infrequent, fire management efforts should be concentrated on predicting days with high probability of a fire. When fires are numerous, management efforts should be concentrated on predicting the number of fires that will occur each day. Examining the number of days having at least one fire (fire-days) and the number of fires per fire-day can provide managers with useful work-load information. We tabulated the number, man-hours to control, and cost data from eight counties in the Scranton area on the basis of fires per fire-day. Most of this more than 2-million-acre area is in the Pocono Mountains Climatic Division (fig.2). One fourth of the days of the year had at least one fire, but during the two major months of the spring fire season, April and May, the area averaged fires on nearly half of the days.

Multiple-fires call for skillful dispatching of fire fighters and equipment plus good communications. The decisions involved with the proper allocation and sudden mobilization of people and equipment necessary to fight large numbers of near simultaneous ignitions are vital. To help make the right decisions, the average number of man-hours required to control fires were computed for days having different numbers of fires per fire-day (fig. 10).

Roughly 8 to 10 man-hours were required to control the average fire when one to five fires occurred on the same day. When six or more fires

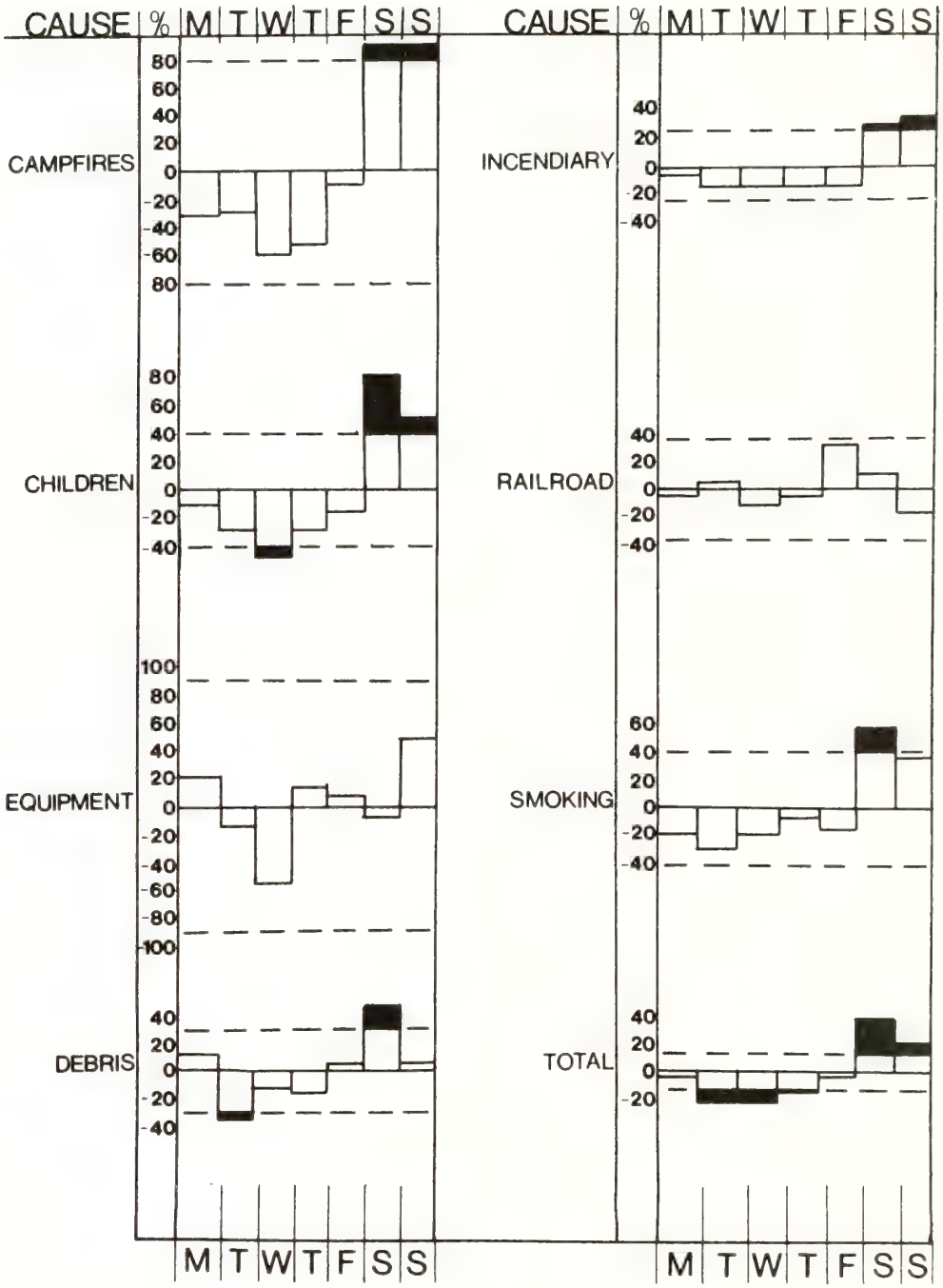
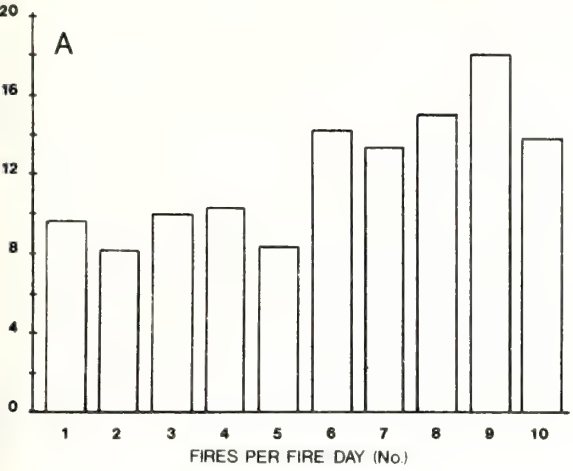
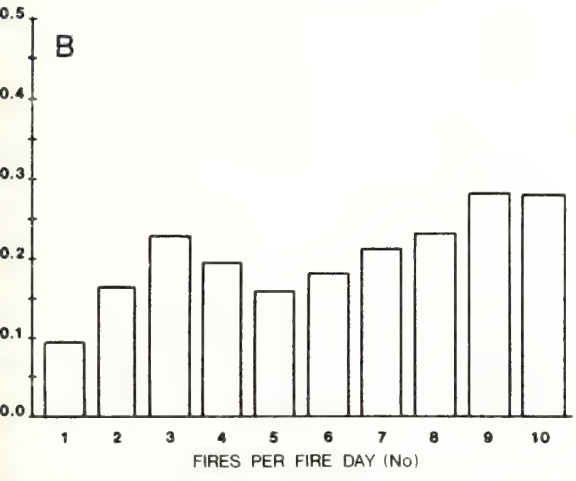


Figure 9.—*Pennsylvania day-of-week fires by cause category, 1970 to 1974. Data are presented as a percentage departure from expected number of fires for each day-of-week. Solid portions of bars show a significant difference at the 0.01 level.*





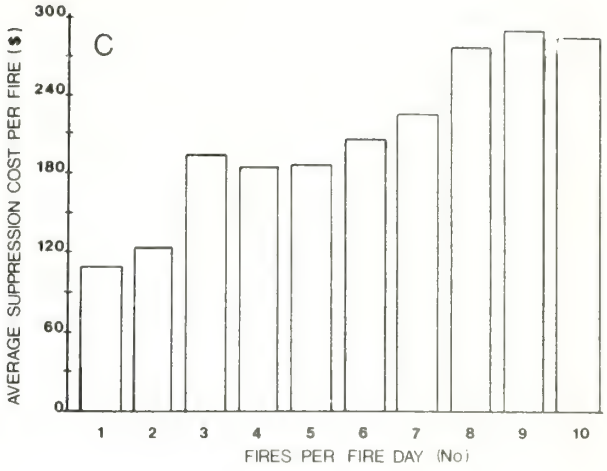


Figure 10.—*Three measures of fire activity based on fires per fire day, Pocono Mountains division, 1962 to 1971:* (A) *number of man-hours required per fire as related to the number of fires per fire day,* (*B*) *number of large fires as related to the number of fires per fire day, and* (*C*) *average suppression cost per fire as related to number of fires per fire day.*

ured on the same day, the number of n-hours to control jumps to 13 to 18. There are reasons for this. First, increased fires per -day reflect increased weather severity, and sequently more control difficulty. Second, npower resources are exhaustible. As the nber of fires increases, there are fewer people ilable to fight each one. Therefore, the ufficient force present at each fire requires a ater total suppression effort because delays in ial attack contribute to increased control time.

Rapid initial attack with adequate manpower l equipment is often the difference between a all or large fire. We can see this relation when examine the ratio of large fires (more than 10 es) to all fires as a function of fires per fire day . 10b). On days when one fire occurred, only of 10 had a large fire. This ratio increased matically as more fires started. On days with e or more fires, an average of 3 was large.

Along with the large fire and manpower problem, suppression cost per fire increased as fires per day increased (fig. 10c). The cost more than doubled between 1 or 2 fires per day versus 8, 9, or 10 fires per day. The manhour profile showed a dramatic difference at five or less fires per day compared to the cases with six or more fires per day. This probably was the point at which the first line of defense was totally committed and secondary forces had to be mobilized.

The concept of the multiple-fire day has a number of planning applications. During a 10-year period with both drought and nondrought seasons (1962-1971) in the Pocono Mountains, 31 percent of the fires and 61 percent of the acreage burned occurred on only 2 percent of the total days—10 percent of the fire days. These are almost the same percentages Haines *et al.* (1973) found in a similar study in Missouri. So, major fire control activity is usually concentrated in a short time span as shown by the following statistics compiled for the Pocono Mountains (fig. 11):

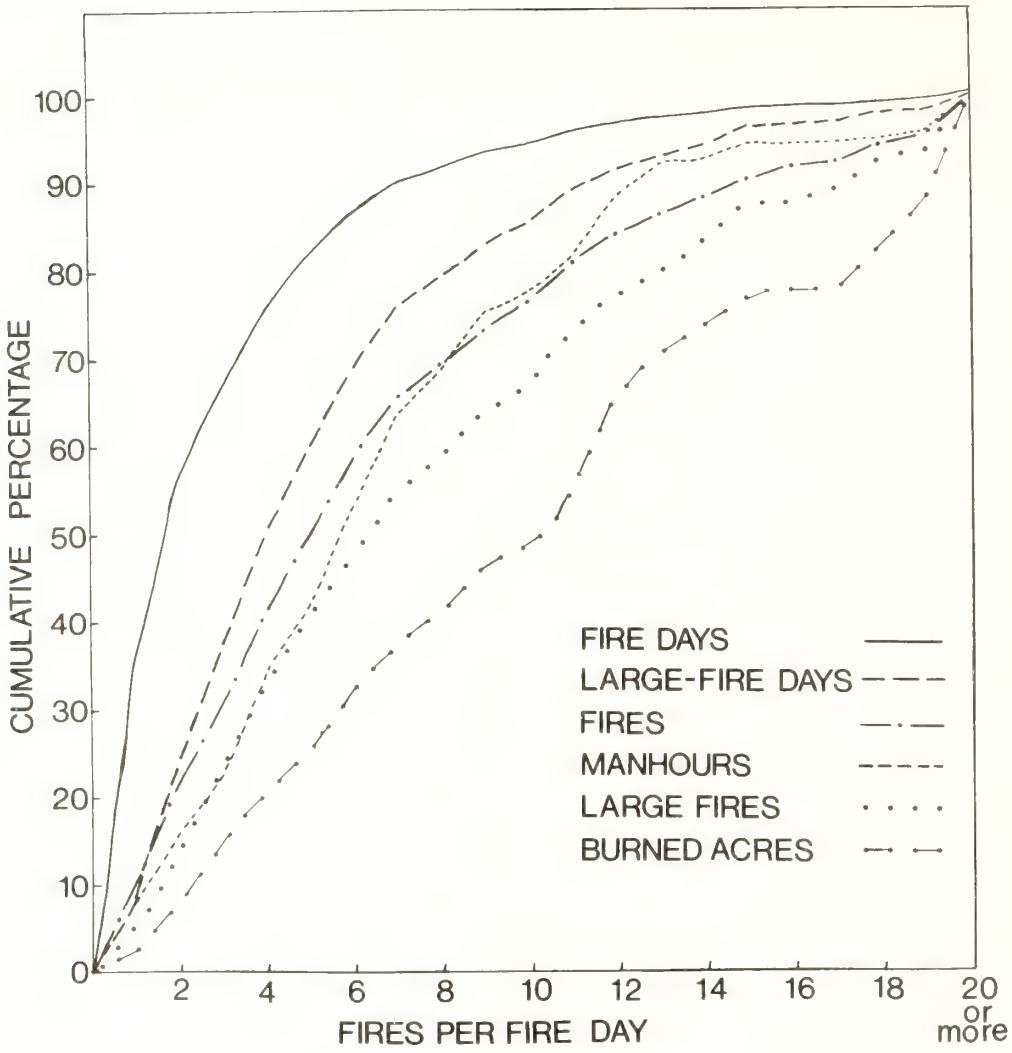


Figure 11.—*Cumulative percent of six measures of fire activity relative to the number of fires per fire day, Pocono Mountains division. Based on 865 fire days with 3,000 wildfires.*

1. Slightly more than half of all fire days had two or more fires.

2. Half of all large-fires days occurred on days when there were four or more fires.

3. Half of all fires occurred on days when there were five or more fires.

4. Half of all man-hours to control were spent on days when there were five or more fires.

5. Half of all large fires occurred on days when there were six or more fires.

6. Half of the burned acreage occurred on d when there were eight or more fires.

Thus, most of the fire control job is compres into a small number of days of intense activ Unfortunately, there is no long-term forecast t tells which days will bring high fire activ Short-term predictions (12 to 36 hours) presently the best that can be made because activity is highly dependent on immed weather.

One especially important factor when mult fires are common is rapid initial attack which le

increased speed of control. Suppression rsonnel and equipment cannot be tied up on one e for a long period because they must be ready handle other fires. Optimum size of crew and ount of equipment, consequently, are critical nsiderations.

FIRE CLIMATOLOGY

ire Danger is a function of the season, a nber of weather elements, fuel availability, and nan activity. The numerical integration of se factors form the basis for the National Fire nger Rating System (Deeming *et al.* 1977). This tem gives the fire manager an indication of tning and man-caused risk, the possibility of ignition and spread, and the potential energy ease rate. Meteorological elements are highly nificant in determining these danger compon-s. Therefore, we tabulated a Pennsylvania fire natology for the principal elements and also for ultant fuel moistures (tables 3-8). Data were en from Scranton weather records, but the ults should apply to most of the State. These a can be used to indicate the climatic bability of being within the bounds of a ning prescription during a given month.

ennsylvania's temperature range is 0°F to °F. The summers are warm—the average is F along Lake Erie to 74°F in southeastern nties. The monthly temperature trends (table show a rapid increase during the spring fire son with 50 percent of the early afternoon dings at or above the upper 30's in March, then easing into and above the low 50's in April. By il temperatures in the 70's are common. From y to October daily temperatures are usually h enough to support intense fire but other ors, mainly lush lower vegetation and the full opy of hardwood trees, inhibit flammability. the autumn fire season the 50th percentile of ly afternoon temperatures again drops into the s. By late November colder afternoon temper-es coupled with shorter days offer little support burning.

he annual relative humidity values show a erent trend (table 4). Values at the 50th centile are highest in December, drop off rapidly during the next 4 months, and are lowest in April. During that month half of the early afternoon relative humidities are at 40 percent or below. This phenomenon has a decided impact on increased severity of the spring fire season because relative humidity affects all components of fire danger.

Windspeed is another highly important meteorological element affecting fire. As well as influencing fire spread, the wind affects the drying rate of fuels and maintains the fire in level terrain. Without a supporting wind there will have been a fire, but not necessarily a fire requiring suppression action. For example, on a calm afternoon fire will spread slowly through an area of leaves and may not be able to maintain itself. On a windy day, however, wind-driven, rolling leaves can quickly scatter fire over a wide area.

A Statewide study of windspeed by 10-day periods during the critical months of March, April, and May showed strongest winds occurring April 1 through April 10.[4] The northwest quadrant of Pennsylvania had the strongest observed windspeeds.

Our data indicate a small but important variation of the 50th percentile of windspeed for the year (table 5). During April, the peak of the spring fire season, the wind is 2 or 3 mph stronger than during the rest of the fire period. Much the same pattern occurs when we examine the windspeeds at the 95th percentile. Higher windspeeds during April, combined with the yearly low relative humidities, increase fire danger. Furthermore, higher windspeeds may make it unsafe for aircraft to fly surveillance flights so the time is lengthened between fire start, detection, and initial attack. And of equal importance, aircraft suppression activities are also affected. So, higher windspeed during April is a major reason why it is Pennsylvania's worst fire month.

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[4]*Sylvern, B.L. 1977. A cumulative frequency distribution of the windspeed throughout Pennsylvania. Unpublished manuscript on file at the NOAA Weather Service Forecast Office, Philadelphia, Pennsylvania.*

Table 3.—*Frequency of temperature values, Scranton, Pennsylvania, 13:00 e.s.t., 1962-1971 (Line separates values at or above a cumulative level of 50 percent)*

(In percent of days in month and cumulative percentage)

Month	Temperatures (°F)															
	[illegible]	[illegible]	[illegible]	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99
January	[illegible]	[illegible]	17	19	7	1	1	(1)	0	(1)	--	--	--	--	--	--
	[illegible]	[illegible]	71	90	97	98	99	100	100	100	--	--	--	--	--	--
February	[illegible]	[illegible]	24	16	8	2	1	1	--	--	--	--	--	--	--	--
	[illegible]	[illegible]	[illegible]	88	96	98	99	100	--	--	--	--	--	--	--	--
March	5	8	14	24	20	10	9	4	3	1	1	1	--	--	--	--
	5	13	[illegible]	51	71	81	90	94	97	98	99	100	--	--	--	--
April	--	--	1	6	12	18	15	16	13	8	4	3	2	1	--	--
	--	--	1	7	19	37	52	68	81	89	93	97	99	100	--	--
May	--	--	--	1	1	4	7	13	17	18	17	13	5	3	1	--
	--	--	--	1	2	6	13	26	43	61	78	91	96	99	100	--
June	--	--	--	--	--	--	1	3	8	15	16	19	23	13	2	--
	--	--	--	--	--	--	1	4	12	27	43	62	85	98	100	--
July	--	--	--	--	--	--	--	(1)	0	7	16	26	28	17	5	1
	--	--	--	--	--	--	--	(1)	(1)	7	23	49	77	94	99	100
August	--	--	--	--	--	--	--	--	5	8	20	30	28	9	1	--
	--	--	--	--	--	--	--	--	5	13	33	63	91	99	100	--
September	--	--	--	--	--	1	3	11	13	16	24	17	11	2	1	--
	--	--	--	--	--	1	4	15	28	45	69	86	97	99	100	--
October	--	--	[illegible]	[illegible]	5	10	12	24	68	15	11	5	1	--	--	--
	--	[illegible]	[illegible]	[illegible]	7	17	29	53	68	83	94	99	100	--	--	--
November	[illegible]	4	8	17	22	19	14	10	4	2	(1)	--	--	--	--	--
	[illegible]	4	12	29	51	70	84	94	98	100	100	--	--	--	--	--
December	22	19	20	15	12	6	3	2	(1)	(1)	--	--	--	--	--	--
	22	41	61	76	88	94	97	99	100	100	--	--	--	--	--	--

[illegible] less than 0.5 percent

Table 4.—*Frequency of relative humidity values, Scranton, Pennsylvania 13:00 e.s.t., 1962-1971 (Line separates values at or above a cumulative level of 50 percent)*

(In percent of days in month and cumulative percentage)

Month	Relative Humidity (Percent)														
	≤14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	≥80
January	2	1	2	1	1	3	5	4	9	10	12	15	8	7	20
	2	3	5	6	7	10	15	19	28	38	50	65	73	80	100
February	1	1	1	1	3	4	5	10	8	12	12	8	6	5	23
	1	[illegible]	3	4	7	11	16	26	34	46	58	66	72	77	100
March	1	(1)	1	4	6	10	9	11	7	10	8	5	6	5	17
	1	[illegible]	[illegible]	6	12	22	31	42	49	59	67	72	78	83	100
April	-	[illegible]	8	8	12	11	11	7	7	5	3	3	4	4	15
	--	2	10	18	30	41	52	59	66	71	74	77	81	85	100
May	(1)	1	2	5	10	14	12	11	7	7	8	3	4	3	13
	(1)	1	[illegible]	8	18	32	44	55	62	69	77	80	84	87	100
June	(1)	(1)	(1)	--	7	9	11	16	5	11	9	10	7	6	9
	-	[illegible]	--	--	7	16	27	43	48	59	68	78	85	91	100
July	--	--	-	[illegible]	5	9	9	12	13	12	8	11	7	4	7
	--	--	--	3	8	17	26	38	51	63	71	82	89	93	100
August	--	--	--	--	1	4	9	14	17	15	7	12	7	7	7
	--	--		--	1	5	14	28	45	60	67	79	86	93	100
September	--	--	--	2	2	4	5	11	15	10	14	10	4	7	16
	--	--	--	2	4	8	13	24	39	49	63	73	77	84	100
October	-	--	(1)	1	5	7	8	13	8	14	11	8	5	5	15
	--		(1)	1	6	13	21	34	42	56	67	75	80	85	100
November	--	-	(1)	1	2	4	6	9	7	12	11	6	6	7	29
	--		(1)	1	3	7	13	22	29	41	52	58	64	71	100
December	(1)	(1)	1	1	1	1	2	5	7	11	13	11	8	10	29
	(1)	(1)	1	2	3	4	6	11	18	29	42	53	61	71	100

[illegible] less than 0.5 percent.

Table 5.—*Frequency of windspeeds, Scranton, Pennsylvania, 13:00 e.s.t., 1962-1971 (Vertical line separates values at or above a cumulative level of 50 percent)*

(In percent of days in month and cumulative percentage)

Month	Wind speeds (m.p.h.)											
	0-3	4-5	6-7	8-9	10-11	12-13	14-15	16-17	18-19	20-21	22-23	≥25
January	14	10	7	14	19	16	6	8	2	2	(1)	2
	14	24	31	45	64	80	86	94	96	98	98	100
February	14	11	5	14	15	16	8	9	4	2	1	1
	14	25	30	44	59	75	83	92	96	98	99	100
March	5	14	5	13	17	18	7	13	5	1	1	(1)
	5	19	24	37	54	72	79	92	97	98	99	100
April	3	11	6	13	14	21	5	14	8	3	(1)	2
	3	14	20	33	47	68	73	87	95	98	98	100
May	3	10	6	17	20	20	7	12	3	1	1	--
	3	13	19	36	56	76	83	95	98	99	100	--
June	3	15	8	27	22	15	3	5	2	--	--	--
	3	18	26	53	75	90	93	98	100	--	--	--
July	4	16	11	19	24	12	6	6	2	--	--	--
	4	20	31	50	74	86	92	98	100	--	--	--
August	3	13	11	26	21	19	3	4	--	--	--	--
	3	16	27	53	74	93	96	100	--	--	--	--
September	6	14	12	19	25	13	5	4	1	1	--	--
	6	20	32	51	76	89	94	98	99	100	--	--
October	9	14	8	20	19	15	5	7	2	1	--	--
	9	23	31	51	70	85	90	97	99	100	--	--
November	10	16	7	17	14	17	8	8	1	2	(1)	--
	10	26	33	50	64	81	89	97	98	100	100	--
December	11	15	5	17	17	11	5	12	3	2	1	1
	11	26	31	48	65	76	81	93	96	98	99	100

[1]Less than 0.5 percent.

Table 6.—*Days since last 0.10 inches or more of precipitation Scranton, Pennsylvania, 1962-1971 (Vertical line separates values at or above a cumulative level of 50 percent)*

(Expressed as number of events, percent of monthly total, and cumulative percentage)

Month	Days since last precipitation event ≥ 0.10 inch																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
January	1	5	1	2	3	3	4	2	2	1	0	2	1	0	0	1	0	0	0	0
	3	17	3	7	10	10	13	7	7	3	0	7	3	0	0	3	0	0	0	7
	3	20	23	30	40	50	63	70	77	80	80	87	90	90	90	93	93	93	93	100
February	3	5	3	6	3	3	1	1	2	2	1	0	2	0	0	0	1	0	0	1
	8	15	9	18	9	9	3	3	6	6	3	0	6	0	0	0	3	0	0	2
	8	23	32	50	59	68	71	74	80	86	89	89	95	95	95	95	98	98	98	100
March	4	5	5	4	2	3	4	1	1	2	2	1	0	1	0	1	0	0	0	3
	10	13	13	10	5	8	10	3	2	5	5	3	0	3	0	2	0	0	0	8
	10	23	36	46	51	59	69	72	74	79	84	87	87	90	90	92	92	92	92	100
April	10	10	4	5	2	3	3	2	0	1	0	2	1	0	0	0	1	0	0	3
	21	21	9	11	4	6	6	5	0	2	0	4	2	0	0	0	2	0	0	7
	21	42	51	62	66	72	78	83	83	85	85	89	91	91	91	91	93	93	93	100
May	5	6	9	3	5	3	4	2	1	1	1	1	0	0	0	1	1	--	--	--
	12	14	21	7	11	7	9	5	2	2	3	2	0	0	0	2	3	--	--	--
	12	26	47	54	65	72	81	86	88	90	93	95	95	95	95	97	100	--	--	--
June	5	7	2	4	4	5	2	2	2	2	0	1	0	1	2	1	0	0	1	--
	12	17	5	10	10	12	5	5	5	4	0	2	0	3	5	2	0	0	3	--
	12	29	34	44	54	66	71	76	81	85	85	87	87	90	95	97	97	97	100	--
July	10	7	5	9	3	2	3	3	0	1	3	0	0	0	2	1	0	0	0	1
	20	14	10	18	6	4	6	6	0	2	6	0	0	0	4	2	0	0	0	2
	20	34	44	62	68	72	78	84	84	86	92	92	92	92	96	98	98	98	98	100
August	6	3	6	6	5	2	1	2	0	1	2	2	1	0	1	0	1	0	0	1
	15	7	15	15	13	5	2	5	0	3	5	5	2	0	3	0	2	0	0	3
	15	22	37	52	65	70	72	77	77	80	85	90	92	92	95	95	97	97	97	100
September	3	2	6	4	2	1	2	7	3	1	1	2	1	0	1	0	0	0	0	1
	8	5	16	11	5	3	6	19	8	3	3	5	3	0	2	0	0	0	0	3
	8	13	29	40	45	48	54	73	81	84	87	92	95	95	97	97	97	97	97	100
October	3	3	7	3	5	2	0	0	0	3	1	2	2	0	0	0	1	0	0	1
	9	9	21	9	15	6	0	0	0	9	3	7	6	0	0	0	3	0	0	3
	9	18	39	48	63	69	69	69	69	78	81	88	94	94	94	94	97	97	97	100
November	7	6	2	9	6	1	5	2	0	0	2	1	0	2	0	2	0	0	0	2
	15	13	4	19	13	2	10	4	0	0	5	2	0	4	0	4	0	0	0	5
	15	28	32	51	64	66	76	80	80	80	85	87	87	91	91	95	95	95	95	100
December	5	6	5	5	1	6	4	0	2	0	3	1	2	1	1	0	1	--	--	--
	12	14	12	11	2	14	9	0	5	0	7	2	5	2	2	0	3	--	--	--
	12	26	38	49	51	65	74	74	79	79	86	88	93	95	97	97	100	--	--	--

Table 7.—*Frequency of 1-hour timelag fuel moistures, Scranton, Pennsylvania, 13:00 e.s.t., 1962-1971 (Vertical line separates values at or above a cumulative level of 50 percent)*

Month	Fuel moisture (Percent)																			
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+	
March	(1)	(1)	2	7	9	14	9	14	11	6	4	2	--	--	--	(1)	--	1	18	
	(1)	1	3	10	19	33	43	57	68	74	78	80	80	80	80	81	81	82	100	
April	--	2	11	15	17	9	9	6	9	3	5	(1)	--	(1)	(1)	--	--	--	14	
	--	2	13	28	45	54	63	69	78	81	86	86	86	86	86	86	86	86	100	
May	(1)	1	5	13	18	12	13	9	7	4	3	1	(1)	--	--	--	--	--	13	
	(1)	1	6	19	37	49	62	71	78	82	85	86	87	87	87	87	87	87	100	
June	--	--	1	8	13	16	16	13	16	4	4	1	(1)	--	(1)	--	--	--	8	
	--	--	1	9	22	38	54	67	83	87	91	92	92	92	92	92	92	92	100	
July	--	--	3	7	9	20	18	11	16	4	4	(1)	--	--	(1)	--	--	--	7	
	--	--	3	10	19	39	57	69	85	89	93	93	93	93	93	93	93	93	100	
August	--	--	(1)	2	7	19	22	16	15	7	4	1	(1)	(1)	--	--	--	--	7	
	--	--	(1)	2	9	28	50	66	81	88	92	93	93	93	93	93	93	93	100	
September	--	--	1	4	6	14	17	16	17	8	2	2	(1)	1	(1)	--	--	1	10	
	--	--	1	5	11	25	42	58	75	83	85	87	87	88	89	89	89	90	100	
October	--	--	1	5	9	17	15	14	17	6	2	2	1	--	--	(1)	--	--	11	
	--	--	1	6	15	32	47	61	78	84	86	88	89	89	89	89	89	89	100	
November	--	--	1	1	6	5	13	18	10	14	8	3	--	1	1	(1)	(1)	(1)	18	
	--	--	1	2	8	13	26	44	54	68	76	79	79	80	81	81	81	82	100	
December	--	--	--	1	1	3	7	14	15	16	5	6	2	1	(1)	(1)	2	--	27	
	--	--	--	1	2	5	12	26	41	57	62	68	70	71	71	71	73	73	100	

[1]Less than 0.5 percent.

Table 8.—*Frequency of 10-hour timelag fuel moistures, Scranton, Pennsylvania, 13:00 e.s.t., 1962-1971 Vertical line separates values at or above a cumulative level of 50 percent*

Month	Fuel moistures (Percent)																	
	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
March	(1)	1	2	5	5	10	11	8	11	11	7	5	2	2	1	--	--	19
	(1)	1	3	8	13	23	34	42	53	64	71	76	78	80	81	81	81	100
April	--	3	9	12	12	10	10	7	4	6	6	2	4	(1)	--	(1)	--	14
	--	3	12	24	36	46	56	63	67	73	79	81	85	85	85	86	86	100
May	(1)	1	5	10	11	15	7	12	7	7	5	3	2	1	(1)	--	--	14
	(1)	1	6	16	27	42	49	61	68	75	80	83	85	86	86	86	86	100
June	--	--	1	4	11	11	13	12	12	14	6	3	3	1	1	--	--	8
	--	--	1	5	16	27	40	52	64	78	84	87	90	91	92	92	92	100
July	--	--	2	5	7	12	15	15	8	15	7	3	3	(1)	(1)	--	--	8
	--	--	2	7	14	26	41	56	64	79	86	89	92	92	92	92	92	100
August	--	--	--	1	3	11	15	18	13	15	9	4	2	1	(1)	(1)	(1)	7
	--	--	--	1	4	15	30	48	61	76	85	89	91	92	92	92	93	100
September	--	--	1	3	5	6	13	12	15	14	9	5	2	2	(1)	1	1	11
	--	--	1	4	9	15	28	40	55	69	78	83	85	87	87	88	89	100
October	--	--	1	4	5	10	12	12	14	12	11	4	2	2	(1)	(1)	--	11
	--	--	1	5	10	20	32	44	58	70	81	85	87	89	89	89	89	100
November	--	--	1	1	4	3	5	12	14	9	11	9	7	3	--	(1)	1	19
	--	--	1	2	6	9	14	26	40	49	60	69	76	79	79	79	81	100
December	--	--	--	1	1	1	3	6	12	8	15	13	3	6	2	(1)	(1)	29
	--	--	--	1	2	3	6	12	24	32	47	60	63	69	71	71	71	100

[1]Less than 0.5 percent

rage yearly precipitation in Pennsylvania s from 36 inches to 48 inches, depending on on. Precipitation, or the lack of it, is an tant feature of fire weather. Generous nts will allow rapid growth of low vegetation enetrate the dead fuels to inhibit combus- Deficits may cause the low vegetation to cure ecome fine fuels.

computed a climatological table of days last precipitation using 0.10 inch as a old value (table 6). The 10 years examined ed both drought and nondrought periods). During the critical spring and autumn fire as rain of at least 0.10 inch occurs at 1- to intervals 50 percent of the time. September d the longest rain-free period. Chances of g as many as 10 consecutive rain-free days 10 inch) in any month was only 10 to 20 nt.

elag is defined as the time necessary for a article to lose approximately 63 percent of fference between its initial moisture content and its equilibrium moisture content (Deeming *et al.* 1977). We will discuss two categories of timelag fuels. One hour fuels consist of dead herbaceous plants and roundwood less than 1/4 inch in diameter. Also included in this category is the uppermost layer of litter on the forest floor. Most fires begin in these fuels. Ten-hour fuels consist of dead fuels of roundwood 1/4 to 1 inch in diameter and the layer of litter extending from just below the surface to 3/4 inch below the surface.

The 1-hour timelag fuel moisture is dependent upon the relative humidity and the temperature. The highest moisture contents in these fuels occur in winter (table 7). Average moisture contents at the 50th percentile level are at 8 or 9 percent from March through October except for readings at 7 percent during April.

The 10-hour timelag fuel moisture may be read directly from wooden fuel analogues or may be computed mathematically from maximum-minimum relative humidity and temperature,

duration of precipitation, and hours of daylight. The month-to-month pattern of moisture content is similar to that of the 1-hour fuel (table 8). Highest moisture contents occur in winter. At the 50th percentile level average moisture contents are at 10 or 11 percent from March through October except for readings at 9 percent during April.

SUMMARY

Fire protection is critical in Pennsylvania because more than 60 percent of the total land area is wooded and much of it is capable of timber production. Pennsylvania also has the largest rural population of any State in the country—3.5 million people.

A tabulation of 60 years of State fire records showed a sharp drop in number of fires since World War II. Also, the ratio of large fires to all fires was about 40 percent in the mid-1940's, but steadily lowered so that it is now about 10 percent.

The major fire season begins in mid-March, peaks in April, and ends in mid-June. There is a second, less severe, fire season that begins in early October and ends in late November.

Campfires showed an impressive reduction as a cause of wildfire, from 64 percent of total in the late 1930's to 3 percent today. Incendiarism has increased dramatically.

Grouping the fire activity data by day-of-week showed that campfires were a special risk on Saturdays as were fires from children, debris burning, incendiarism, and tobacco smoking. Campfires, children fires, and incendiarism were also high on Sundays.

The multiple-fire day is highly indicative of the dynamics of fire suppression. One-fourth of the days of the year had at least one fire in the Pocono Mountains, but during April and May the area averaged fires on nearly half of the days. One-third of the fire days produced one fire; two-thirds of the fire days had three fires or less; the remainder of the fire days had from 4 to 28 fires. Roughly 9 to 10 man-hours were required to control the average fire when one to five fires occurred on the same day. There was a sudden jump to 13 to 18 man-hours per fire when six or more fires occurred on the same day.

The fire climatology of the State fo pattern seen throughout much of the nort United States. The major impact of elements occurs during April, the peak of season.

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HOW TO EXTRACT AND CHARACTERIZE DEHYDROGENASES FROM WOODY PLANTS

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Forest biology research increasingly explores physiological mechanisms that control tree growth in order to discover physiological bases for selecting strains that yield more or better wood (Gordon 1971, Wolter and Gordon 1975). Such studies may require knowledge of metabolic changes that cause or accompany variations in growth of the tree and differentiation of tissues. Metabolic changes can be estimated by various means, which include quantifying variations in the activities and types of enzymes (Firenzuoli *et al.* 1968, Barnett and Naylor 1969). Interest has also recently increased in genetic analysis of trees through study of isoenzymes (Conkle 1971a, 1971b; Feret 1971, 1978; Feret and Stairs 1971a, 1971b; Hamaker and Snyder 1973, Juo and Stotzky 1973).

Enzyme analysis is possible only if enzyme extraction can be exactly reproduced and the enzymes stablized for hours or days, as governed by analytical methods. Extraction and stabilization of enzymes from animals, lower plants, and herbaceous plants have been extensively investigated because these organisms are long time subjects of biological research. Only more recently has interest arisen in the enzymes of woody plants. Therefore, least is known of extracting and stabilizing their enzymes.

Methods developed for securing and stabilizing enzymes from other organisms have been tried on trees with limited success. Thus, most studies with woody plants have only involved enzymes that are relatively stable in crude extracts. Less stable enzymes may prove more indicative of physiological status or genetic constitution.

Best results have been obtained when enzymes were extracted during or shortly after tree seed germination, or when leaves were used (see earlier references). Woody tissues are difficult to disrupt without physically destroying enzymes. Disrupted woody tissues release tannins and phenols that promptly denature enzymes, either directly or after enzymatic oxidation. Thorough extraction and stabilization of enzymes from woody tissues assume importance because difficulties in disruption often make it impossible to use large amounts of tissue to offset deficiencies in technique.

Thus, we have extensively examined methods for the extraction, stabilization, and characterization of dehydrogenases from woody plants. Results and previously unpublished data are summarized here as an aid to other investigators, many of whom have contacted us seeking further, more detailed information concerning application of our findings.

Our studies have yielded methods for extraction and stabilization of dehydrogenases through prolonged periods of characterization. These methods can be applied, with suitable modifications, to other enzymes.

The first section deals with methods, for those readers who are interested only in technique; the second section discusses the rationale for the methods, and cites supporting evidence. Previously unpublished supportive technique data have been included, as have typical results to be expected from various techniques.

METHODS

Collection

Collect samples by clipping pieces or punching out discs with, for example, a leather punch. Immediately place tissue in standard lyophil containers or in 4-dram screw cap vials. The latter fit 1/2-inch diameter Virtis port fittings. Freeze tissue in a mixture of dry ice and acetone (-86C), acetone-filled mechanically refrigerated bath (-90C), or, preferably, in liquid nitrogen (-196C). Do not cover the samples with water before freezing, or allow acetone to leak into the containers. Collect samples in the field by freezing in powdered dry ice, or (preferably) in liquid nitrogen. Keep samples cool during transport.

Lyophilize samples for 15 to 24 hours. Resinous tissue may require longer drying times unless containers are less than half full. Check the lyophil for proper operation by lyophilizing a water sample, which should remain frozen until the ice has sublimed. Melting indicates an improperly constructed or functioning unit.

Storage

Store samples, if necessary, at -20C or less in plastic bags or jars that contain anhydrous calcium sulfate or a molecular sieve. Samples store best in a cabinet cooled with dry ice, or in a mechanically refrigerated ultra-low temperature freezer. Always store over desiccant.

Milling

Mill samples to pass a 20-mesh screen of a Wiley mill. Very small samples can be collected by aspirating the milling chamber (Haissig 1972). Samples should be milled just before homogenization, if possible. Milled tissue should be stored at the lowest possible temperature, over desiccant, in evacuated or inert gas-filled containers, such as vacuum desiccators.

Homogenization

Technique

All operations are performed at about 5C in a cold room. Place from 10 to 50 mg of milled tissue in a V-bottom glass homogenizer (Duall, Kontes Glass Co., Vineland, New Jersey 08360)[1]. Add 2 ml of buffer (see below) and suspend the tissue with a small spatula. Homogenize the sample for 30 to 45 seconds with a motorized (1100 rpm) glass pestle. A suitable apparatus is available commercially (Kontes Glass Co.) or can be easily constructed. In either instance, the user must supply a rheostat (Powerstat, Superior Electric Co., Bristol, Connecticut 06010) and timer (Gralab Model 300, Dimco-Gray Co., Dayton, Ohio 45402) to control speed and duration of homogenization. Rinse tissue adhering to the pestle into the homogenizer with 1 ml of buffer. Mix contents of homogenizer and decant into centrifuge tube. Centrifuge at 40,000 to 100,000 xg for 30 minutes at 5C. Transfer samples to 1 dram screw cap vials. Certain homogenates contain lipid-like substances that float on the supernatant, even after prolonged centrifugation at 100,000 xg. Supernatants can be freed of these substances by withdrawing supernatant with a syringe from below the floating layer.

Buffers

Use 100 mM Tris-HCl,[2] pH 7.5, containing 5 percent (w/v) glycerol, 100 mM EtSH, and 1 mM NAD (or NADP). Substitute 1 mM DTT for EtSH, and increase nucleotide coenzyme concentration to 10 to 50 mM if electrophoresis will be conducted without prior removal of the higher concentration

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[1] *Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.*

[2] *Abbreviations: EtSH—mercaptoethanol, DIECA—diethyldithiocarbamate, DTT—dithiothreitol, NAD—nicotinamideadenine dinucleotide, NADP—nicotinamideadenine dinucleotide phosphate, AP—ammonium persulfate, TEMED—N,N,N',N', tetramethylethylene-diamine, PVP—insoluble polyvinylpyrollidone (Polyclar AT), G-3-PD—glyceraldehyde-3-phosphate dehydrogenase (E.C. 1.2.1.12), G-6-PD—glucose-6-phosphate dehydrogenase (E.C. 1.1.1.49), 6-PGD—6-phosphogluconate dehydrogenase (E.C. 1.1.1.44), MD—malate dehydrogenase (E.C. 1.1.1.37), PPO—phenolase (E.C. 1.10.3.1), PR—peroxidase (E.C. 1.11.1.7), MES—(2[N-Morpholino] ethane sulfonic acid, HEPES—N-2-Hydroxyethylpiperazine-N'-2-ethanesulfonic acid, Tris—Tris (Hydroxymethyl) aminomethane, BSA—bovine serum albumin.*

f EtSH. Affinity chromatography requires buf-
ers of low ionic strength. Use 10 to 25 mM
IEPES - NaOH, pH 7.5, containing 20 percent
w/v) glycerol and 10 mM DTT.

Purification and Characterization

Numerous methods exist for the partial purifica-
on and characterization of enzymes. The follow-
ng methods afford a starting point from which
nore detailed analyses begin.

crylamide Gel Electrophoresis

Equipment consists of a Bio-Rad Model 150
Bio-Rad Laboratories, Richmond, California
4804) electrophoresis cell, or equivalent, and a
ompatible power supply.

Allow gel solutions to warm to room tempera-
ure. Add 25 mg of AP to 25 ml of running gel
olution while the latter is being stirred. Quickly
dd 1.2 ml of the solution to each 5 mm (I.D.) x
25 mm acid washed gel tube and layer distilled
ater over the acrylamide solution. Use a 5 ml
lastic syringe that has been fitted with a 6 cm
iece of 1/32-inch I.D. teflon tubing. After
olymerization, add 0.2 ml of spacer gel solution
o each tube, and then withdraw the solution with
he syringe. Flush 25 ml of spacer gel solution
ith nitrogen gas for 15 seconds. Stir the solution
nd add 25 mg of AP. Add 0.2 ml of this solution
o the top of each running gel tube and layer with
ater. Allow polymerization. Install the tubes in
he cell, add electrode buffer, and apply sample.

From 100 to 400 µl of sample are added to each
ube with a micro syringe (Drummond Scientific
o., Broomall, Pennsylvania 19008). Apply about
50v until samples have entered the running gel,
fter which voltage can gradually be increased to
bout 250v (about 2.5 ma per tube). Colored
mpurities usually run at the front, which obviates
eed for a tracking dye. If necessary, add a small
mount of bromphenol blue to each sample or to
he upper electrode buffer.

Remove gels from tubes and stain by standard
nethods (Brewer 1970). Trials are necessary to
alance amount of sample applied and duration of
taining. Always include controls (eliminate sub-
trate or coenzyme) to check for non-enzymic
eduction of tetrazolium dye.

Blue background and diffuse banding in gels can be reduced or eliminated by exposing gels to stain for 15 to 30 minutes at 5C in darkness, then decanting staining solution. A good scanning-further reduction of dye for up to 15 hours at 5C in darkness. Do not add water or buffer after decanting staining solustion. A good scanning-recording device markedly simplifies and improves data collection (e.g., attachment to Pye-Unicam SP 1800 spectrophotometer).

Extracts sometimes do not contain sufficient enzyme for a satisfactory staining reaction. In such instances, increase the volume of extract added to the gel, or concentrate the sample by $(NH_4)_2SO_4$ precipitation (see later), Minicon B-15 or A-25 membrane concentrators (Amicon Corp., Lexington, Massachusetts) (Hicks and Haissig 1974), or Molecular Separators (Millipore Corp., Bedford, Massachusetts 01730).

Salting-out

Assay the crude extract for enzyme activity and measure the volume (v_1). Add crystalline $(NH_4)_2so_4$ to the cold extract. The initial percentage (w/v) of $(NH_4)_2SO_4$ should not precipitate the enzyme of interest but should precipitate many of the other macromolecules in solution. Usually from 50 to 80 percent $(NH_4)_2SO_4$ effects initial precipitation.

Allow the mixture to stand for several hours at 5C to insure complete precipitation. Centrifuge (40,000 xg, 30 minutes), decant the supernatant, and save the pellet. Assay and measure the volume of the supernatant (V_2). Dissolve the pellet in a measured amount of extraction buffer (V_3) and assay.

Make the supernatant 100 percent (at 5C) in $(NH_4)_2SO_4$ again by adding crystalline salt and allow the mixture to stand for several hours. Centrifuge, decant, and save the supernatant. Save the pellet. Measure the volume of supernatant (V_4) and assay. Dissolve the pellet in 1 ml of extraction buffer (V_5) and assay.

Calculate the total units of enzyme activity in V_1 through V_5 in order to determine changes in activity at each step. If activity is found in V_3 or V_4, adjusting $(NH_4)_2SO_4$ concentrations will rectify the situation. A suitable schedule places most of the initial activity in V_2, then V_5.

V_5 can be freed of salts by dialysis against extraction buffer, but this step is often unnecessary.

Gel Filtration

Columns of 75 cm x 2.5 cm and longer often yield the best results. Select a packing material, such as Sephadex G-150 (Pharmacia Fine Chemicals, Inc., Piscataway, New Jersey 08854), with a molecular weight exclusion limit greater than the estimated molecular weight(s) of the enzyme(s) of interest. Hydrate the gel according to manufacturer's instructions in extraction buffer. Decant the fines several times, and thoroughly degass the room-temperature gel suspension with an aspirator. Coenzymes can be excluded from buffer in preparation of the gel and packing of the column to reduce cost.

Stabilize the gel bed by pumping buffer through the column overnight. The peristaltic pump should be set for a flow rate that will not collapse the gel bed but will give a suitably fast elution. These conditions are determined empirically.

Apply about 1 ml of enzyme solution to the column and elute at the predetermined flow rate with freshly prepared extraction buffer. Collect fractions of about 5 to 10 ml volume.

Assay the fractions for enzyme activity, and do electrophoresis on samples from desired tubes. Concentrate samples, if necessary or desired, by $(NH_4)_2SO_4$ precipitation or with membrane concentrators.

Column Electrofocusing

We use LKB equipment, which includes 110 ml column, ampholyte solutions, power supply, fraction collector, gradient mixer, and peristaltic pump (LKB Instruments, Inc., Rockville, Maryland 20852). A Radiometer model 26 pH meter and 0-14 pH miniature combination electrode are used to measure pH of each fraction at the collection temperature (London Co., Westlake, Ohio 44145 and Sargent-Welch Scientific Co., Skokie, Illinois 60076).

Our procedures closely follow the manufacturer's recommendations, with important exceptions that are noted under Reagents.

Fractions collected after electrofocusing, like those from gel filtration, can be further analyzed by electrofocusing, acrylamide gel electrophoresis, gel filtrations, or other established methods.

Affinity Chromatography

Various proprietary media exist for affinity chromatography of dehydrogenases (P-L Biochemicals, Inc., Milwaukee, Wisconsin 53205 Bio-Rad Laboratories, Richmond, California 94804). Specificity of the media varies and may profoundly influence the quality of results, so care should be used in selection.

Purification of G-3-PD from jack pine seedlings is a typical example of affinity chromatography.

Agarose-hexane-NAD Type 1 (P-L Biochemicals) is washed free of glycerol and sodium azide with extraction buffer. The agarose is then slurried into a column constructed from a 5 ml disposable plastic syringe barrel. A porous, hydrophilic, polypropylene disc at the bottom of the syringe barrel retains the agarose (Bolab, Inc., Derry, New Hampshire 03038). Commercial columns are also available (Isolab, Inc., Akron, Ohio 44321). Settled medium is further washed with extraction buffer to stabilize the bed. Settled bed volume is about 4 ml.

Samples are homogenized and the crude extract is assayed for enzyme activity. A known volume (about 2 ml) of crude extract is applied to the column after the buffer in the column has been run almost into the bed. Crude extract is then run slowly into the bed, and the column is washed at full flow rate with about 25 ml of extraction buffer. Effluent volume is measured and enzyme activity determined. The column is then eluted at full flow rate with extraction buffer that contains 10 mM to 25 mM NAD. Fractions of 1 or 2 ml volume are collected and assayed for enzyme activity.

Enzyme activity at all stages is recorded as total Δ OD min (Δ OD/min/0.1 ml x number of 0.1 ml volumes per fraction). Thus total enzyme activity can be accounted for at each step, and gains or losses in activity will be apparent.

Fractions are subjected to further analysis or purification at once.

Columns are cleaned for reuse by washing with several bed volumes of: 50 mM MES-NaOH, pH 5.5, containing 2.0 M NaCl and 0.1 percent BSA; then, 50 mM Tris-HCl, pH 8.5, containing 2.0 M NaCl and 0.1 percent BSA; and finally, extraction buffer. Columns thus treated can be reused many times. Periodic resuspension of the medium with nitrogen gas aids removal of foreign materials and prevents marked decreases in flow rate.

REAGENTS
Extraction Buffer

Weigh 50 gm of glycerol into a 1000 ml beaker. Add 750 ml distilled water, 12.1 gm Tris, and 7.0 ml EtSH. Insert a glass electrode, stir the solution, and adjust the pH to 7.5 with concentrated HCl. Make up to 1 liter with distilled water. The resulting solution is 100 mM in Tris, 5 percent in glycerol, and 100 mM in EtSH. Store frozen at -20C.

Add NAD or NADP to a portion of thawed buffer just before use. Do not store buffer containing NAD or NADP.

Add 2.38 gm HEPES to 750 ml distilled water that contains 200 gm of glycerol. Insert a glass electrode, stir the solution, and adjust pH to 7.5 with 1.0 N NaOH. Make up to 1 liter. The resulting solution is 10 mM in HEPES and 20 percent in glycerol. Store frozen at -20C. Add 77.2 mg of DTT per 50 ml of thawed buffer just before use. The resulting buffer is 10 mM in DTT. Check pH. Do not store buffer containing DTT for more than a day.

Electrophoresis Electrode Buffer

Dissolve 12.1 gm Tris and 58.0 gm glycine in 500 ml of distilled water, and make up to 2 l. The resulting buffer is 50 mM in Tris. Dilute each part of buffer with 9 parts of distilled water before use. Insert a glass electrode and adjust pH of the solution to 8.3 by adding crystalline Tris or glycine.

Electrophoresis Spacer Gel

Dissolve 60.6 gm Tris in 750 ml of distilled water. Add 40 gm Cyanogum-41 and 1 ml TEMED. Insert a glass electrode, stir, and adjust pH of the solution to 6.7 with concentrated HCl, then dilute to 1 liter. The resulting solution is 500 mM in Tris. Refrigerate.

Electrophoresis Running Gel

Dissolve 60.6 gm Tris in 750 ml of distilled water. Add 80 gm Cyanogum-41, and 1 ml TEMED. Insert a glass electrode, stir, and adjust pH of the solution to 8.5 with concentrated HCl, then dilute to 1 liter . The resulting solution is 500 mM in Tris. Refrigerate.

Electrofocusing Density Gradient Solutions

Heavy Fraction

Weigh 36 gm glycerol into a 100 ml beaker, and add 25 ml of distilled water. Stir in 0.4 ml EtSH and 1.8 ml of pH 3-10 ampholyte (LKB) solution. Make up to 50 ml with distilled water.

Light Fraction

Add 0.6 ml of pH 3-10 ampholyte solution and 0.4 ml EtSH to 20 ml of distilled water. Add a measured amount of enzyme extract and make up to 50 ml with distilled water.

DISCUSSION
Collection

Under many circumstances, samples are too numerous, or are collected too far from the laboratory to allow extraction of fresh tissues. It may be easier to transport tissue frozen in dry ice or in liquid nitrogen and lyophilize at the laboratory. Lyophilization of samples eliminates problems connected with sample milling and storage, as long as the enzyme of interest is not cold labile. Moreover, fast freezing of tissues before lyophilization increases extraction of certain enzymes or does not markedly lower extracted activity (Haissig and Schipper 1972).

Successful lyophilization depends upon very fast freezing of the sample and a perfectly functioning lyophil. Sample containers must be rapidly aspirated so that samples remain frozen

until all moisture has sublimed. The condenser must effectively collect water vapor so that samples dry thoroughly before removal. Samples are being vacuum dried, not lyophilized, unless these conditions are met.

Storage

Enzyme activities decline in stored tissues, with the highest rates of decline related to elevated temperatures, moisture levels, and oxygen levels. Assay of enzymes extracted from samples readily detects such decline. However, our observations indicate that qualitative changes apparently occur in enzyme molecules upon storage even though activity has not detectably declined. Qualitative variations may markedly influence electrophoretic characterization. Isoenzyme bands become increasingly diffuse with prolonged storage of tissue. Lyophilization magnifies the problem, apparently because of freezing. Whatever the reason, lyophilization somewhat decreases the sharpness of electrophoretic separations. Enzymes extracted from fresh tissue produce the best electrophoretic results, but practicality may necessitate devising a storage method that is applicable to the tissue and enzyme of interest.

Milling

Homogenization of whole tissues, other than leaves, root tips, and buds, has proven impractical (Haissig and Schipper 1972). Enzyme activities are lost or markedly lowered before woody tissues are fully disrupted. Enzyme activity may be obtained in such extracts, but never the highest attainable activity. Fracturing tissues frozen with liquid nitrogen or an acetone-dry ice mixture is generally less effective and more expensive than milling (Haissig and Schipper 1972).

Unfortunately, milling increases surface area of the sample, and thereby exposes enzymes to oxygen, moisture, and air-borne denaturants. Storage conditions for milled tissues must consequently be more rigorous than conditions for unmilled tissue. Inert gases, such as welding grade nitrogen, adequately shield well dried, milled tissues that are maintained at -20C or lower.

Homogenization

Duall (Kontes Glass Co.) homogenization of milled, lyophilized tissues has proven superior to homogenization of tissues that have been dehydrated or pulverized by other methods. Duall homogenization is fast, reproducible, and yields quantifiable enzyme activities where suitable extraction media are used (Haissig and Schipper 1972). In particular, quantifiable enzyme activities are obtained from very small samples (10 to 50 mg) of even difficult to disrupt tissue such as xylem. The method is only semiquantitative, but exceeds other methods in enzyme recovery because the sample is well contained, and easily transferred to centrifuge tubes. More sample is lost adhereing to the surface of a conventional mortar and pestle than is required for Duall homogenization. In addition, samples need not be strained before centrifuging. However, the method requires practice. Inexperience in operation of the Duall homogenizers invariably results in too little or too much homogenization, with concommitent low yields of enzyme activity. Practice until a peak enzyme activity can be reproduced for a given type of sample.

In addition, homogenizer size must be exactly 7 ml. Smaller pestles do not withstand the needed force, and larger homogenizers are difficult to keep cool. If needs dictate more extract, supernatants should be pooled after homogenization, or another method of homogenization should be developed.

Extraction Media

The extraction medium solubilizes and, hopefully, stabilizes the enzyme molecules. Any component of the extraction medium that does not have a demonstrable effect on solubility or stabililty should be eliminated (Haissig and Schipper 1972). Untested additives complicate buffer preparations, increase costs, and often subsequently prove deleterious or valueless. In addition, additives may interfere with subsequent steps of purification or characterization. Additives that have been tested singly may have different effects when used in combinations.

Similarly, pH, chemical composition, and ionic strength of buffers should be adjusted with

urpose, never arbitrarily. Elevation of ionic trength or use of monionic detergents may elease so-called bound enzyme fractions (Haissig nd Schipper 1971, 1972; Shipper 1975), which ıay or may not meet experimental objectives. At ımes an arbitrarily selected buffer and ionic trength may inadequately buffer a tissue extract, s shown by pH measurements with a glass lectrode.

Extraction media for enzymes from plant issues have usually been designed to protect nzymes from tannins (Goldstein and Swain 1965) r phenols or from polymeric brown pigments that ɔrm after the oxidation of phenols by phenolase Haissig and Schipper 1975a and references herein). Plant tissues usually contain sufficient henols and phenolase so that, in the presence of ıolecular oxygen, brown pigments form in xtracts, and co-precipitate with enzymes (table). The pigments may not form immediately in issue extracts of some species, but in others, such s extracts of *Salix fragilis* stem tissue, distinct ɔrowning occurs during homogenization. Consequently, enzymes may be completely denatured ɔefore an initial assay can be done unless ɔreventive measures are used.

Various methods have been used to prevent ormation of brown pigments (Haissig and Schipɔer 1971, 1972, 1975a). Of these, addition of nsoluble PVP has been widely employed. PVP ıdsorbs tannins and phenols. Reasonable

Table 1.—*Estimation of phenolics (as phenol) and phenolase (PPO) activity in woody and herbaceous plants*

Species	Type of tissue	Phenolics $\bar{x}$ µg ± S.E. per mg dry weight	PPO Units ± S.E. per gm dry weight
Woody			
Aspen	Dormant twig	32 ± 0.7	348 ± 12
Black walnut	" "	20 ± 0.4	84 ± 24
Barberry	" "	16 ± 0.5	144 ± 0
Red pine	" "	15 ± 0.1	167 ± 24
Sugar maple	" "	14 ± 0.5	36 ± 0
White spruce	" "	13 ± 0.5	312 ± 48
Silver maple	" "	10 ± 2.0	276 ± 53
Nonwoody			
Collards	Leaves	22 ± 0.7	252 ± 21
Spinach	"	17 ± 0.7	288 ± 2
Barley	"	5 ± 0.2	1,064 ± 98
Sweet potato	Tuber	4 ± 0.1	156 ± 67
Tomato	Stem & leaves	4 ± 0.1	347 ± 14
Control			
Mushroom	Cap	13 ± 0.3	2,988 ± 101

amounts of PVP remove all tannins from aqueous solution but not phenols (fig. 1). Moreover, PVP treatment may enhance phenolase activity (table 2) and reduce activity of desired enzymes (Haissig and Schipper 1975a). However, other methods of removing tannins and phenols, such as using anion exchange resins or celluloses, are less desirable than PVP either in removal of tannins or phenols or in maintaining desired enzyme activity (Haissig and Schipper 1971, 1975a) (fig. 2). Thus, adding PVP is a good starting point for enzyme stabilization, except for particular instances where it inhibits enzyme activity (Haissig and Schipper 1975a).

A further step in enzyme stabilization consists of blocking formation of brown pigments by continually reducing quinones that are generated from phenols by phenolase. Reduction of quinones prevents their condensation and prevents formation of brown pigments as long as sufficient reducing agent is present (fig. 3).

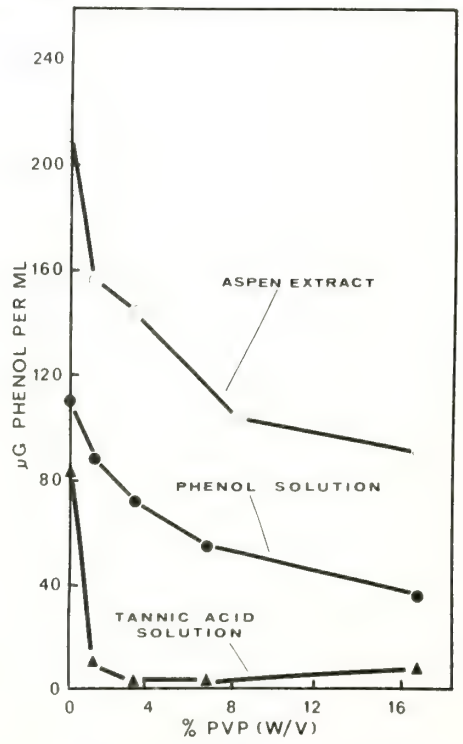

Figure 1.—*Effect of PVP during tissue homogenization on removal of phenolics from aspen extracts and on removal of phenol and tannic acid from aqueous solution. The decrease in the level of phenolics in the aspen extract between 0 and 1.7 percent (w/v) PVP probably results from the removal of tannins.*

Table 2.—*Comparison of phenolase (PPO) activity in extracts of woody and herbaceous plants prepared with and without 1.7 percent (w/v) polyvinylpyrrolidone (PVP)*

Species	Type of tissue	Ratio units per gm dry weight + PVP / - PVP
Woody		
Sugar maple	Dormant twig	6.0
Black walnut	" "	5.9
Aspen	" "	2.4
White spruce	" "	1.3
Barberry	" "	1.2
Silver maple	" "	0.9
Red pine	" "	0.8
Ginkgo	" "	0.7
Herbaceous		
Tomato	Stem & leaves	2.4
Sweet potato	Tuber	2.0
Collards	Leaves	2.0
Spinach	"	1.4
Barley	"	0.8
Control		
Mushroom	Cap	0.9

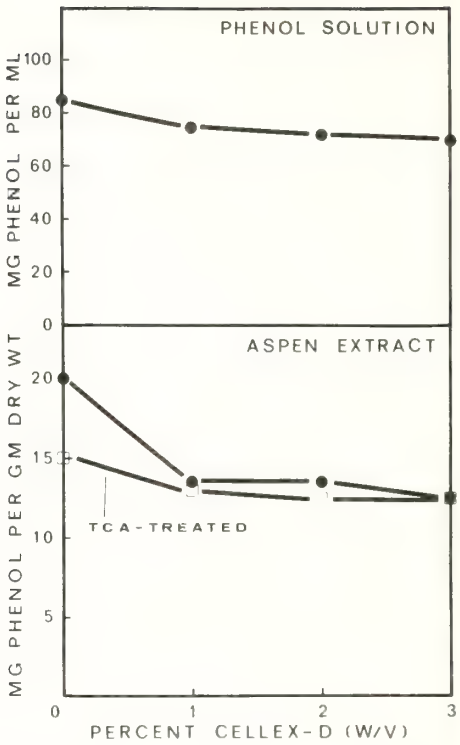

Figure 2.—*Effect of DEAE cellulose on removal of phenol from aqueous solution and aspen extracts. Extracts were prepared with buffer containing 0.1 percent (w/v) bovine albumin and DEAE cellulose and were (TCA) or were not treated with an equal volume of 10 percent trichloroacetic acid before phenolics were estimated. Note that more than 1 percent (w/v) DEAE cellulose removes differences between TCA- and non-TCA-treated aspen extracts, which indicates removal of bovine albumin from non-TCA extracts.*

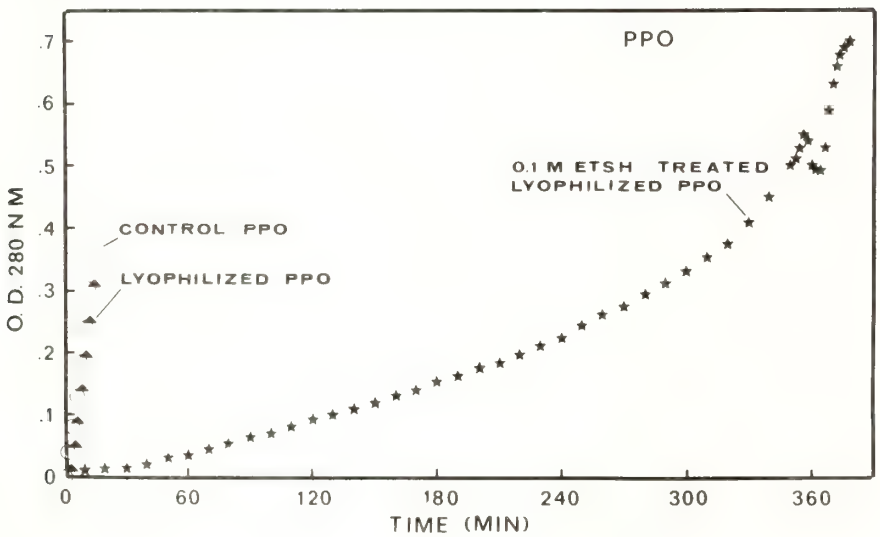

Figure 3.—*Influence of mercaptoethanol (EtSH) on mushroom phenolase (PPO) activity. Full enzyme activity is restored by lowering the concentration of EtSH by lyophilization. The effect of low levels of EtSH and other reducing agents, is overcome after quinones generated by PPO activity oxidize the reducing agent.*

Cysteine, DIECA, EtSH, and DTT reduce quinones. However, cysteine tends to autoxidize, which greatly shortens the life of buffers that contain cysteine. DIECA may reduce activity of desired enzymes in comparison with no treatment (fig. 4) or EtSH or DTT treatment (Haissig and Schipper 1975a) (fig. 5). In our experience, about 10 mM EtSH or 1 mM DTT prevent formation of brown pigments, even during prolonged experiments, but higher concentrations are often required to maximize desired enzyme activity (Haissig and Schipper 1975a, 1975b) (fig. 6). Neither EtSH or DTT inhibit desired enzyme activity in concentrations of at least 100 mM.

Combined PVP-EtSH treatments have proved effective in securing and retaining dehydrogenase activity, except G-3-PD activity (table 3). PVP treatment strongly inhibits G-3-PD activity initially or speeds loss of activity in comparison with EtSH alone. Other dehydrogenases may perform similarly.

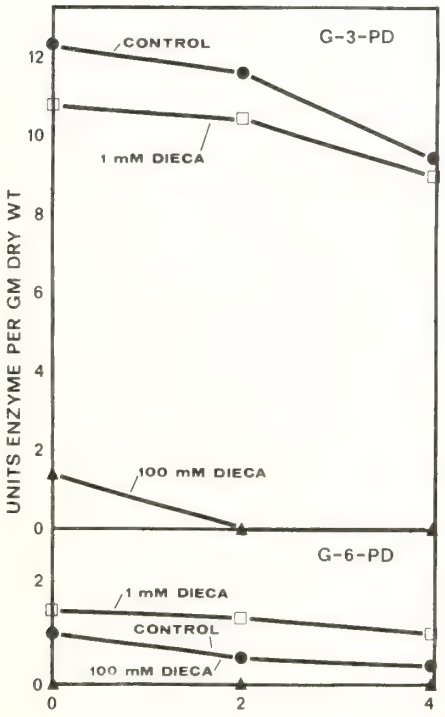

Figure 4.—*Influence of diethyldithiocarbamate (DIECA) in the extraction buffer on the activity of glyceraldehyde-3-phosphate (G-3-PD) and glucose-6-phosphate (G-6-PD) dehydrogenases in aspen extracts.*

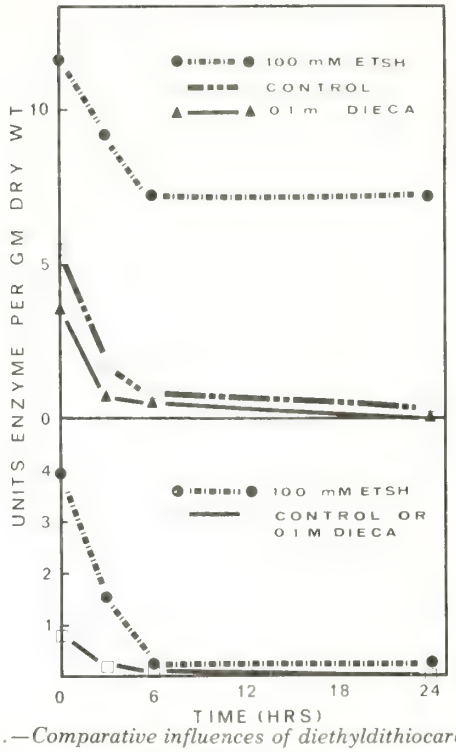

Figure 5.—*Comparative influences of diethyldithiocarbamate (DIECA) and mercaptoethanol (EtSH) in the extraction buffer on the activity of glyceraldehyde-3-phosphate (G-3-PD, upper graph) and glucose-6-phosphate (G-6-PD, lower graph) dehydrogenases in aspen extracts.*

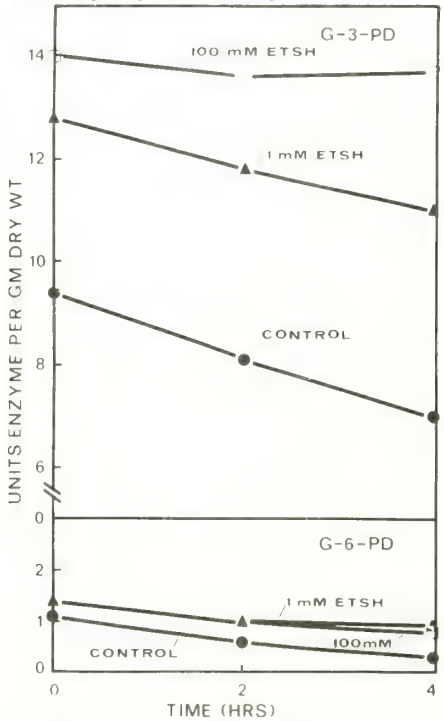

Figure 6.—*Influence of mercaptoethanol (EtSH) in the extraction buffer on the activity of glyceraldehyde-3-phosphate (G-3-PD) and glucose-6-phosphate (G-6-PD) dehydrogenases in aspen extracts.*

Table 3.—*Influence of insoluble polyvinylpyrrolidone (PVP) and mercaptoethanol (EtSH) on decay of sweet potato dehydrogenase activity*

Treatment	$\bar{x}$ units[1] per gram dry weight by enzyme and time							
	6-PGD		G-6-PD		G-3-PD		MD	
	0 hrs	72 hrs	0 hrs	72 hrs	0 hrs	72 hrs	0 hrs	72 hrs
Control	0	0	0.2	0	0	0	0.7	0
1.7 percent PVP	0.6	0	4.0	2.5	2.0	1.0	3.5	2.8
3.3 percent PVP	0.6	0	5.4	3.0	1.7	1.1	5.0	3.4
100 mM EtSH	2.3	1.9	8.7	1.2	67.7	31.4	13.0	1.6
100 mM EtSH + 1.7 percent PVP	2.4	2.2	9.8	2.9	70.4	18.1	15.4	13.6
100 mM EtSH + 3.3 percent PVP	2.2	2.1	9.4	3.5	62.6	15.5	14.0	13.2

[1]Standard errors of means did not exceed ± 7 percent.

The combined PVP-EtSH treatment frequently increases initial enzyme activities, but activity of some dehydrogenases is retained over the long term only by additional treatment. Our experience with these third-order treatments has been limited primarily to dehydrogenases, but the principles probably apply equally to any enzyme that catalyzes product formation from two or more reactants.

Addition of one of the reactants to the extraction buffer stablizies long-term activity (Haissig and Schipper 1975b). Although the actual cause remains unclear, the extraction of dehydrogenases in the presence of PVP (3 percent), a reducing agent (10 to 100 mM), and oxidized nucleotide coenzyme (1 mM or more) markedly enhances initial and long-term activity in comparison with PVP-reducing agent treatment alone (Haissig and Schipper 1975b) (figs. 7 and 8).

Including a higher concentration of oxidized nucleotide coenzyme (10 to 50 mM) allows a reduction in concentration of reducing agent (1 to 10 mM). Lower concentrations of reducing agent make possible the electrophoresis of samples, which, if prepared with 100 mM EtSH or 10 mM DTT, would cause high background in gels that are stained with tetrazolium dyes.

Purification, Concentration, Characterization

Purification invariably results in loss of enzyme and an increase in specific activity. Unfortunately, loss of enzyme cannot be afforded when initial amounts of enzyme are small, as often occurs when extracting woody tissue. A mode of purification must be sought that yields pure enough enzyme to meet experimental objectives and simultaneously yields a suitable quantity of enzyme in an appropriate volume of buffer. Purification must usually be followed by concentration of enzyme because most methods of purification dilute the sample.

Membrane concentrators will reduce almost any volume of enzyme solution. However, concentration may wholly denature enzyme, or yield

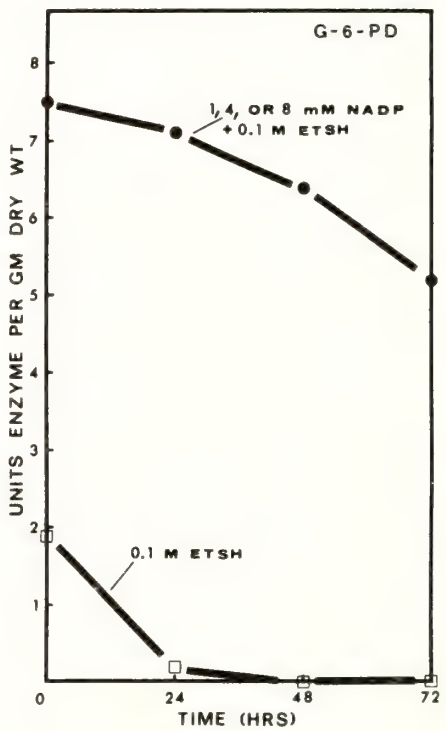

Figure 7.—*Influence of NADP in extraction buffer on G-6-PD activity with time in crude aspen extracts.*

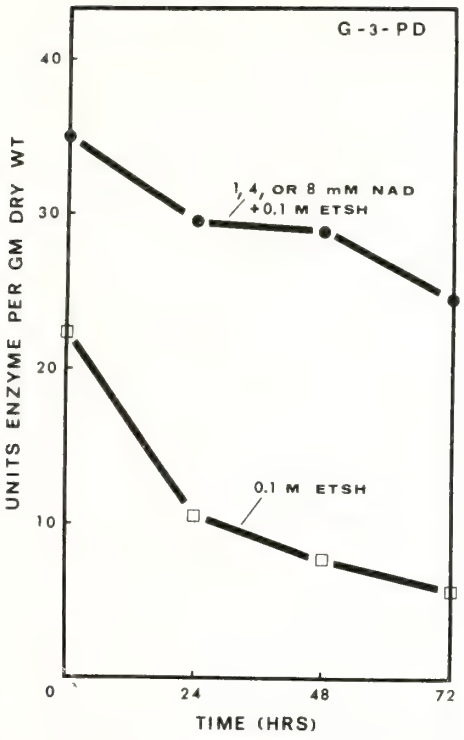

Figure 8.—*Influence of NAD in extraction buffer on G-3-PD activity with time in crude aspen extracts.*

olutions with enzyme activity that is out of roportion to the reduction in volume (table 4). oncentration may also produce syrups. Preliminry trials should test conditions of concentration o that desirable results are obtained.

Dialysis frees an enzyme of low-molecularveight substances and may enhance specific ctivity upon removal of inhibitors. We have ound dialysis particularly useful in cleansing xtracts before further purification. In particular, ialysis seems to remove phenolics that tend to mit life of gel filtration columns. However, ctivity losses during prolonged dialysis often xceed half of initial activity unless the buffer is arefully selected for stabilization characteristics nd flushed with nitrogen gas during dialysis. ast dialysis equipment can also be used.

Ammonium sulfate precipitation has proven seful because it simultaneously purifies and oncentrates the enzyme. Again, however, loss of nzyme activity may be great because complete recipitations at the various stages of fractionaon require time during which enzyme denatures.

Table 4.—*Influence of 10-fold volume reduction by Minicon -A25 concentrators on enzyme activity per unit volume of extract*

Enzyme	Species	Specific activity[1]		Increase in specific activity per unit volume[2]
		Initial	Final	
PR	Aspen	66.5 ± 1.2	442.0 ± 31.8	6.6
	Jack pine	10.9 ± 0.1	62.8 ± 9.0	5.8
	Paper birch	60.5 ± 4.0	599.3 ± 9.6	9.9
	Black spruce	18.6 ± 1.1	148.3 ± 3.0	8.0
	White spruce	11.0 ± 0.0	103.6 ± 8.0	9.4
G-3-PD	Aspen	15.1 ± 0.2	76.9 ± 0.6	5.1
	Jack pine	0.7 ± 0.0	2.2 ± 0.2	3.1
	Paper birch	0.3 ± 0.0	0.0 ± 0.0	0.0
	Black spruce	1.6 ± 0.1	11.1 ± 1.0	6.9
	White spruce	1.0 ± 0.0	2.61± 0.4	2.6
MD	Aspen	8.6 ± 0.3	118.8 ± 6.2	13.8
	Jack pine	3.3 ± 0.2	17.7 ± 1.3	5.4
	Paper birch	2.1 ± 0.1	8.5 ± 1.7	4.0
	Black spruce	1.2 ± 0.1	22.7 ± 2.1	18.9
	White spruce	0.6 ± 0.0	10.1 ± 0.0	16.8
G-6-PD	Aspen	2.7 ± 0.2	17.6 ± 2.9	6.5
	Jack pine	0.5 ± 0.0	3.1 ± 0.2	6.2
	Paper birch	0.3 ± 0.0	1.4 ± 0.2	4.7
	Black spruce	0.8 ± 0.0	4.5 ± 1.1	5.6
	White spruce	0.6 ± 0.0	3.4 ± 0.1	5.7
6-PGD	[3]			

[1]Mean units per gram dry weight per 100 µl extract ± standard errors of three replications.
[2]Experimental conditions should have theoretically yielded a 10-fold increase in specific activity per unit volume because the initial sample volume was reduced by one-tenth, and no measurable activity losses occurred in unconcentrated portions of the extracts during the experiment.
[3]No activity detectable in concentrated extracts.

In addition, loss of enzyme occurs unless precise concentrations of ammonium sulfate are determined for each fractionation step. In spite of certain disadvantages, ammonium sulfate fractionation works for small volumes of extract, once acquaintance is gained with the method.

Gel filtration yields best results when small volumes of relatively clean extract are used—for example, enzyme purified and concentrated by ammonium sulfate fractionation. The method will both purify and characterize and has a unique capability for approximating molecular weight. Two disadvantages of the method are the length of time that is required to elute enzyme from large columns and the large effluent volume in which enzyme is obtained. However, a high degree of purification may be obtained and specific activity may increase, so that more activity is eluted from the column than was applied (fig. 9).

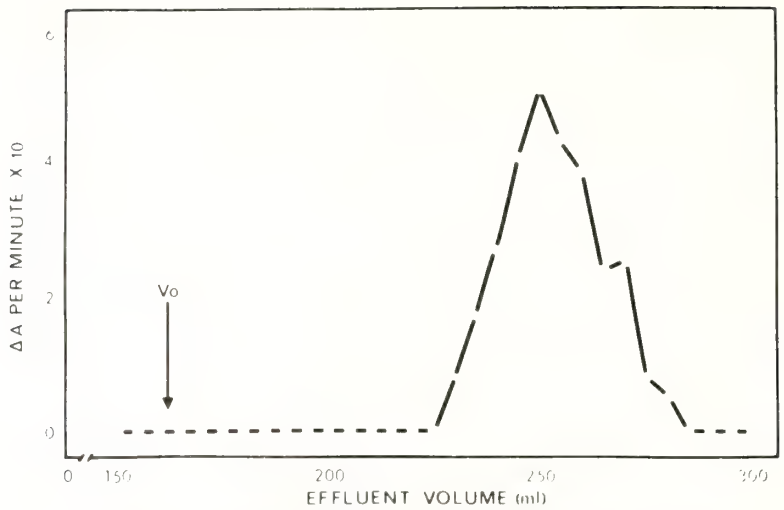

Figure 9.—*Separation of G-3-PD from jack pine seedlings (192 hours) on sephadex G-150. 1.92 U of G-3-PD were applied to column, and 2.58 U were recovered, for a 134 percent increase in activity.*

Column electrofocusing, like gel filtration, works best with clean enzyme preparations. Suitably prepared columns provide highly reproducible determinations of isoelectric point and enzyme or isoenzyme separations based thereon (fig. 10). The primary disadvantages of the method that we have encountered are prolonged times to properly focus enzyme and isoelectric precipitation of the enzyme of interest or other molecules in the extract. In addition, half or more of initial enzyme activity may be lost during the long focusing times. And, of course, power failures of even short duration destroy separations.

Affinity chromatography affords a theoretically superior method for enzyme purification because highly specific medium-enzyme combinations can be used. In addition, purified enzyme is obtained in a relatively small effluent volume, which can be less than the applied volume of enzyme solution (fig. 11).

Excellent separations can be obtained with small columns, which allow working with small volumes of extract, such as those volumes used for characterization by gel electrophoresis. However, it cannot be assumed that affinity chromatography

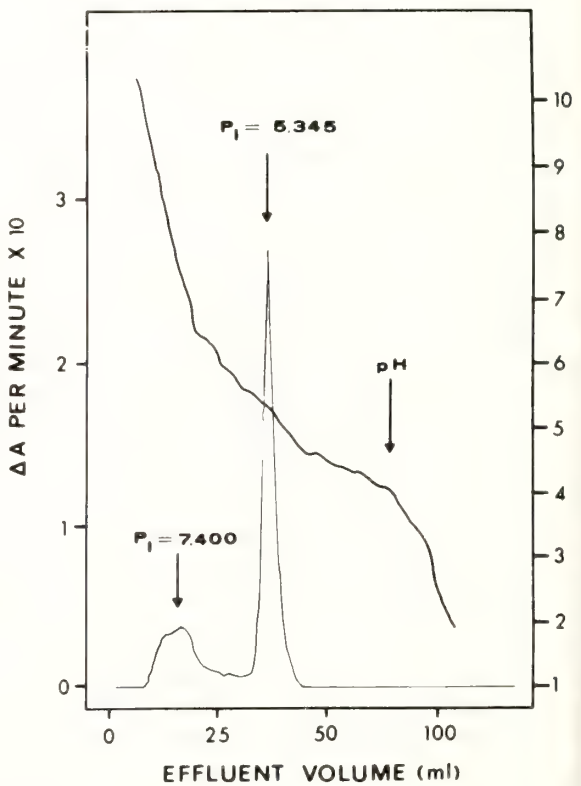

Figure 10.—*Column electrofocusing of G-3-PD (days, 2 percent LKB ampholyte, 300v). 15.97 U of G-3-PD were applied to column, and 8.57 U were recovered, for a 46 percent loss in activity*

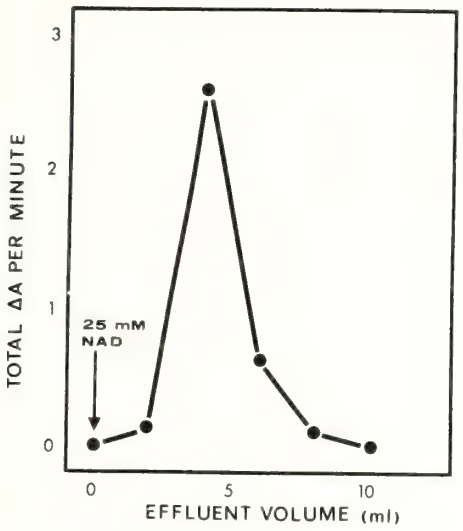

Figure 11.—*Affinity chromatography of G-3-PD from jack pine seedlings. Wash contained 29.4 percent of applied activity, effluent contained 69.5 percent and 1.1 percent was not accounted for.*

utomatically results in a high or even usable level f purification, as might be predicted on a heoretical basis. First, impurities may elute at pH nd ionic strength similar to those that elute nzyme. Second, we have found that under some onditions, a large fraction of the enzyme mole-ules may be irreversibly or nearly irreversibly onded to impurities during extraction. This raction of the population, though bound to npurities, may show high catalytic activity in wet ssays both before and after affinity chromato-raphy (Haissig and Schipper 1977).

Best results may be obtained only by preventing onding of impurities to enzyme during extraction r by removing impurities before chromato-raphy. A workable approach at these stages may, owever, be vexing to obtain. As an alternative, nzyme of high purity (presumably the uncon-aminated portion of the population) may be btained by collecting the earliest elution volume ith activity. All fractions with activity cannot be ooled using this approach, and much enzyme is ost.

Gel electrophoresis, and modifications such as el electrofocusing, have become standard tech-iques for the simultaneous purification and haracterization of enzymes in woody plants and ther extracts. Discontinuous acrylamide disc gel lectrophoresis provides good resolution of soenzymes (fig. 12). Slab acrylamide gel electro-horesis has been much less useful to us,

Figure 12.—*Acrylamide gel electrophoretic separation of G-3-PD from jack pine seedlings (48 hours) showing three isozymes. Peaks S, R, and F are start of spacer gel, start of running gel, and frontal bands, respectively.*

apparently because the amount of power applied denatures too much enzyme for use with extracts that are basically low in enzyme activity.

In general, crude extracts have been prepared and electrophoresed without either purification or determination of activity before assay. In our experience, this approach has serious faults, at least in the study of dehydrogenases.

Enzyme may be completely denatured during electrophoresis, but presumed absent from the extract. Moreover, the degree of purity of enzyme in crude extract may vary with developmental stage of the plant, organ, or tissue from which enzyme was extracted. Thus, the density and number of isoenzymes found may vary with developmental stage or physiological status, but not because of a true relation between the enzyme and metabolic levels or rates. Rather, the new chemical composition of the crude extract may have modified the structure or catalytic ability of the enzyme to create an artifact. Such occurrences are possible, for example, when levels of phenolics vary in crude extracts. However, other low-molecular-weight chemicals may also modify structure or catalytic activity.

The basic approach to electrophoresis must be cautious. Available methods of purification seem to preclude the need to use unassayed, crude initial extracts.

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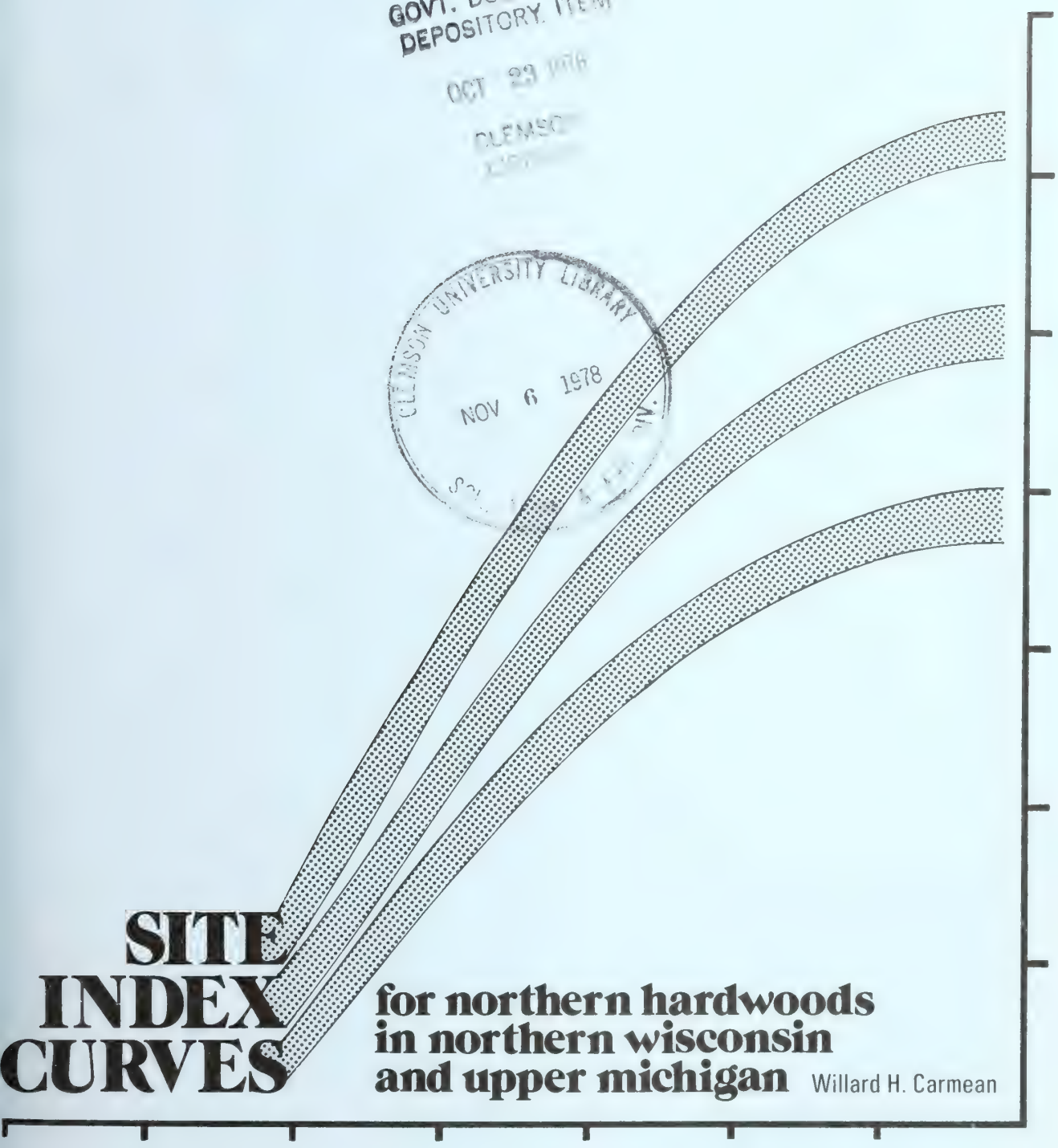

SITE INDEX CURVES

for northern hardwoods in northern wisconsin and upper michigan

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1978

SITE INDEX CURVES FOR NORTHERN HARDWOODS IN NORTHERN WISCONSIN AND UPPER MICHIGAN

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St. Paul, Minnesota

Northern Hardwoods are among the more nportant and widespread forest types found in astern hardwood forests and cover about 10 illion acres in the Lake States (USDA Forest ervice 1973). Characteristic species are sugar aple[1] (*Acer saccharum* Marsh.), red maple (*A. ubrum* L.), and yellow birch (*Betula alleghanien-s* Britton). In certain areas American beech *Fagus grandifolia* Ehrh.), American basswood *Tilia americana* L.), American elm (*Ulmus nericana* L.), and white ash (*Fraxinus americana* .) are important stand components. Other pecies that occur less frequently in northern ardwood stands are black ash (*F. nigra* Marsh.), lack cherry (*Prunus serotina* Ehrh.), northern red ak (*Quercus rubra* L.), paper birch (*B. papyrifera* Iarsh.), bigtooth aspen (*Populus grandidentata* Iichx.), and quaking aspen (*P. tremuloides* Iichx.).

One of the first steps for intensively managing orests is to determine the site quality of the land or different tree species. The site index method is ne most widely accepted means for estimating te quality in the United States and Canada Carmean 1975, 1977). This method of site valuation requires (a) suitable trees for the eeded height and age measurements, and (b) ccurate site index curves applicable to local soil nd site conditions.

Satisfactory site index estimates can be taken nly from dominant and codominant trees that ave been free-growing and uninjured throughout neir lives. Such trees are most commonly found in ven-aged, fully stocked stands that have not been isturbed by past harvesting, repeated burning, r heavy grazing. In the Lake States the original orthern hardwood stands were usually uneven in age. Dominant and codominant trees in these old growth stands generally are unsuited for site evaluation because they originated as understory trees, and thus have been subjected to periods of suppression. However, extensive stands of young, even-aged northern hardwoods also occur in the Lake States; they originated after clearcutting or heavy harvest cutting 40 or more years ago. Dominant and codominant trees in such stands are well suited for site index estimation.

Accurate site index curves are lacking for most of the species found in the Lake States northern hardwood forests (Carmean 1977). For many species existing site index curves are based on limited data collected from other regions, or are older harmonized curves not based on precise stem analysis methods. The goal of this study was to construct site index curves suitable for accurate site quality estimation for 13 tree species commonly found in the northern hardwood stands of the Lake States.

THE DATA

Data were collected from 204 plots located in northern Wisconsin and Upper Michigan (fig. 1). Most plots were located on the Chequamegon, Nicolet, Ottawa, and Hiawatha National Forests, but several were located on nearby State and private land.

All plots were approximately 1/5-acre in size and were established in fully stocked, even-aged northern hardwood stands that were between 41 and 105 years of age; dominant and codominant trees on each plot had an age range of no more than 10 years. Several tree species usually occurred on each plot, and for each species one to six dominant and codominant trees were used to estimate site index. Each tree selected for site

[1] *Tree names follow Little (1953).*

determination was felled and the bole was sectioned at about a 6-inch stump height, at 2 feet, at 4.5 feet, and at 4-foot intervals thereafter up the bole. Annual rings were carefully counted on the disks that were cut at each section point.

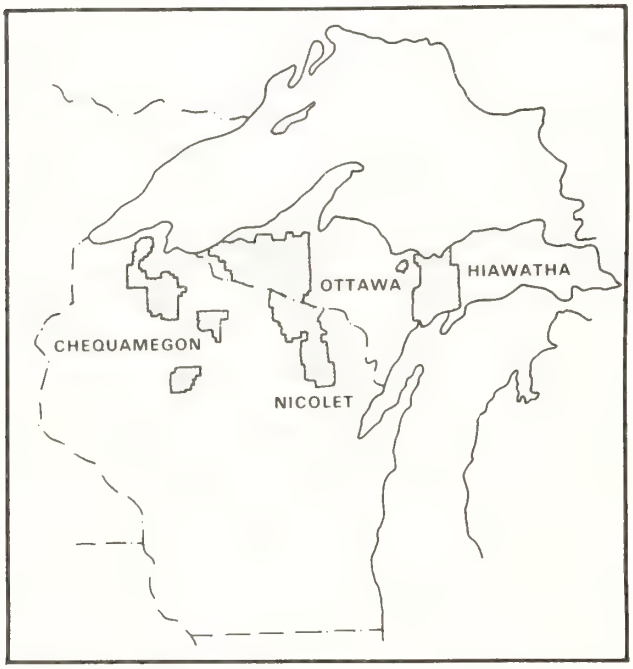

Figure 1.—*Site index curves for northern hardwood species are based on stem analysis data taken from plots located on the Chequamegon, Nicolet, Ottawa, and Hiawatha National Forests of northern Wisconsin and Upper Michigan. Additional plots were located on nearby State and private lands.*

Individual tree height-age curves were plotted using annual ring counts from each section. Trees that showed signs of early suppression, top breakage, or dieback were discarded from the analysis; trees also were discarded if ring counts revealed that they exceeded the defined 10-year range in age for even-aged stands. A total of 3,402 dominant and codominant trees were used for computing site index curves for the 13 hardwood species (table 1).

COMPUTATIONS AND RESULTS

Procedures followed were similar to those used for computing site index curves for upland oaks in the Central States (Carmean 1972, [2]). Briefly, age at breast height (4.5 feet) was used as the starting point for all height-age curves to eliminate the early erratic growth that occassionally occurs. Then age at breast height was converted to total age by adding a constant of 4 years. Tree height-age curves for each species were averaged on each plot, and plots were stratified into 5-foot site index classes (table 1). For each species tree height at successive 5-year intervals was read from the average height-age curves; these are the values used for the subsequent site curve computations. Separate nonlinear height-growth

[2]*Carmean, Willard H. 1978. Site index curves for northern hardwoods in the Lake States. Unpublished manuscript on file at the North Central Forest Experiment Station, St. Paul, Minnesota.*

Table 1.—*Number of plots and trees by site index class used in constructing site index curves for 13 species commonly found in second growth northern hardwood forests of northern Wisconsin and Upper Michigan*

Species	Site index class									Total
	<43	43-47	48-52	53-57	58-62	63-67	68-72	73-77	>77	
	Total number of plots[1]									
Sugar maple	2(9)	8(27)	25(105)	35(139)	54(220)	33(140)	18(76)	2(5)		177(721)
Red maple	1(4)	5(18)	19(77)	22(77)	36(145)	21(77)	9(37)	1(3)		114(438)
Yellow birch	3(9)	3(10)	11(37)	30(116)	38(157)	22(82)	10(42)	2(6)		119(459)
American beech		2(6)	6(23)	7(27)	4(14)					19(70)
American basswood		3(9)	5(17)	14(48)	23(87)	37(154)	31(131)	6(22)	3(15)	122(483)
American elm		3(11)	7(26)	14(52)	24(87)	22(80)	26(107)	12(48)	1(5)	109(416)
White ash		2(7)	2(10)	5(15)	10(35)	18(57)	19(86)	12(50)	5(15)	73(275)
Black ash			4(13)	6(24)	11(39)	6(20)	8(33)	3(13)	1(1)	39(143)
Black cherry	1(3)	2(9)	3(10)	7(19)	5(14)	14(48)	5(12)	4(8)	1(3)	42(126)
Northern red oak			2(3)	3(15)	11(42)	15(49)	5(23)	1(4)		37(136)
Paper birch		1(2)		8(22)	6(18)	7(20)	8(31)			30(93)
Aspens[2]				2(7)	4(13)	2(5)	1(2)	2(5)	2(10)	13(42)
Total	7(25)	29(99)	84(321)	153(561)	226(871)	197(732)	140(580)	45(164)	13(49)	894(3,402)

[1]Numbers in parentheses are the number of trees sectioned.
[2]Data combined for bigtooth and quaking aspens.

ssion equations were then computed for each lass. General nonlinear height-growth re- on equations combining all data also were ated for the 13 hardwood species using observed tree height and age data and the method of least squares. The resulting equations[2] were used to compute the site index curves for the 13 species (figs. 2-13).

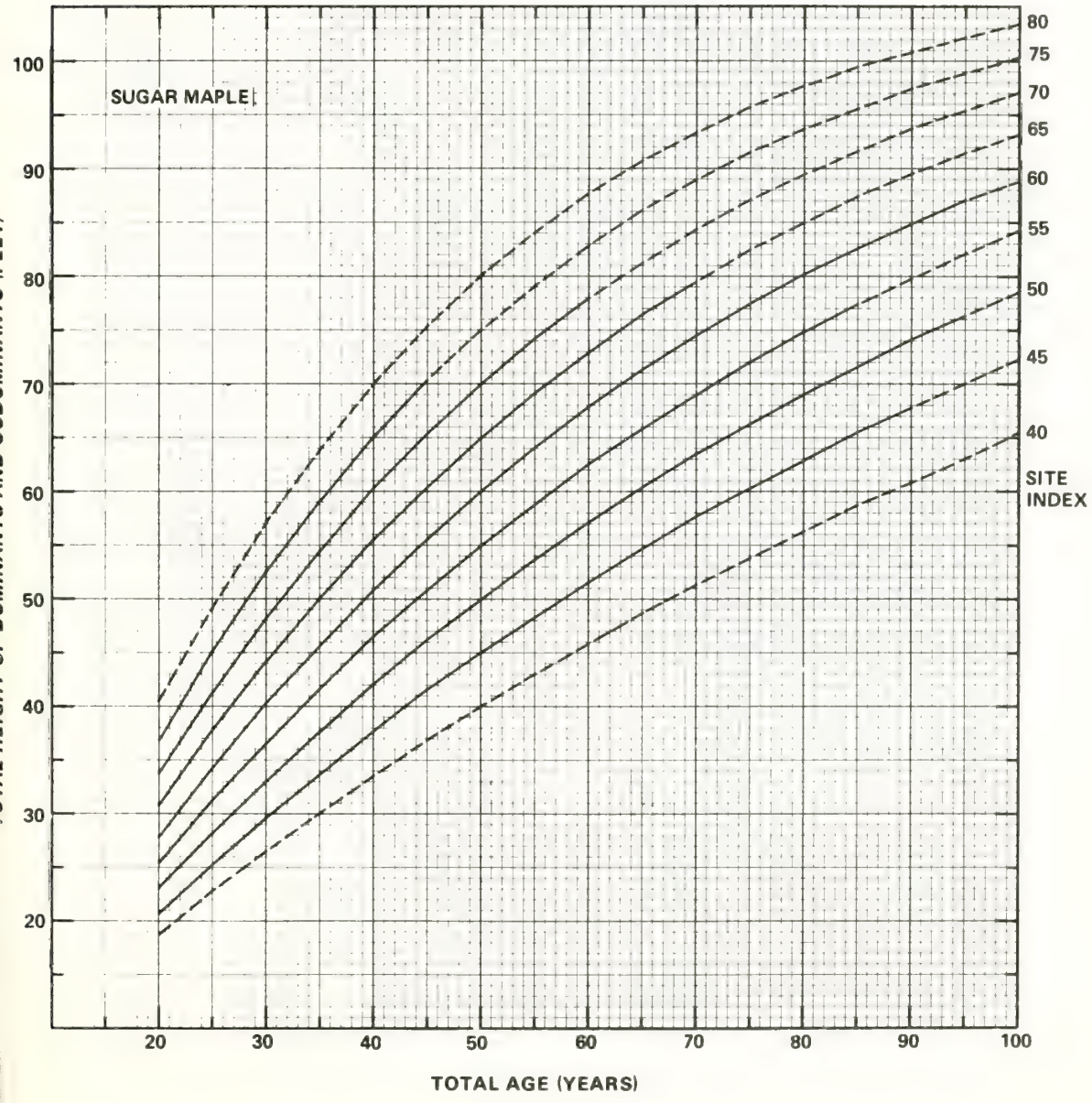

Figure 2.— *Site index curves for sugar maple in northern Wisconsin and Upper Michigan. These curves are based on stem analyses of 721 dominant and codominant trees growing in 177 plots. Add 4 years to breast-height age to obtain total age. Dashed lines indicate extrapolations beyond actual observed data.*

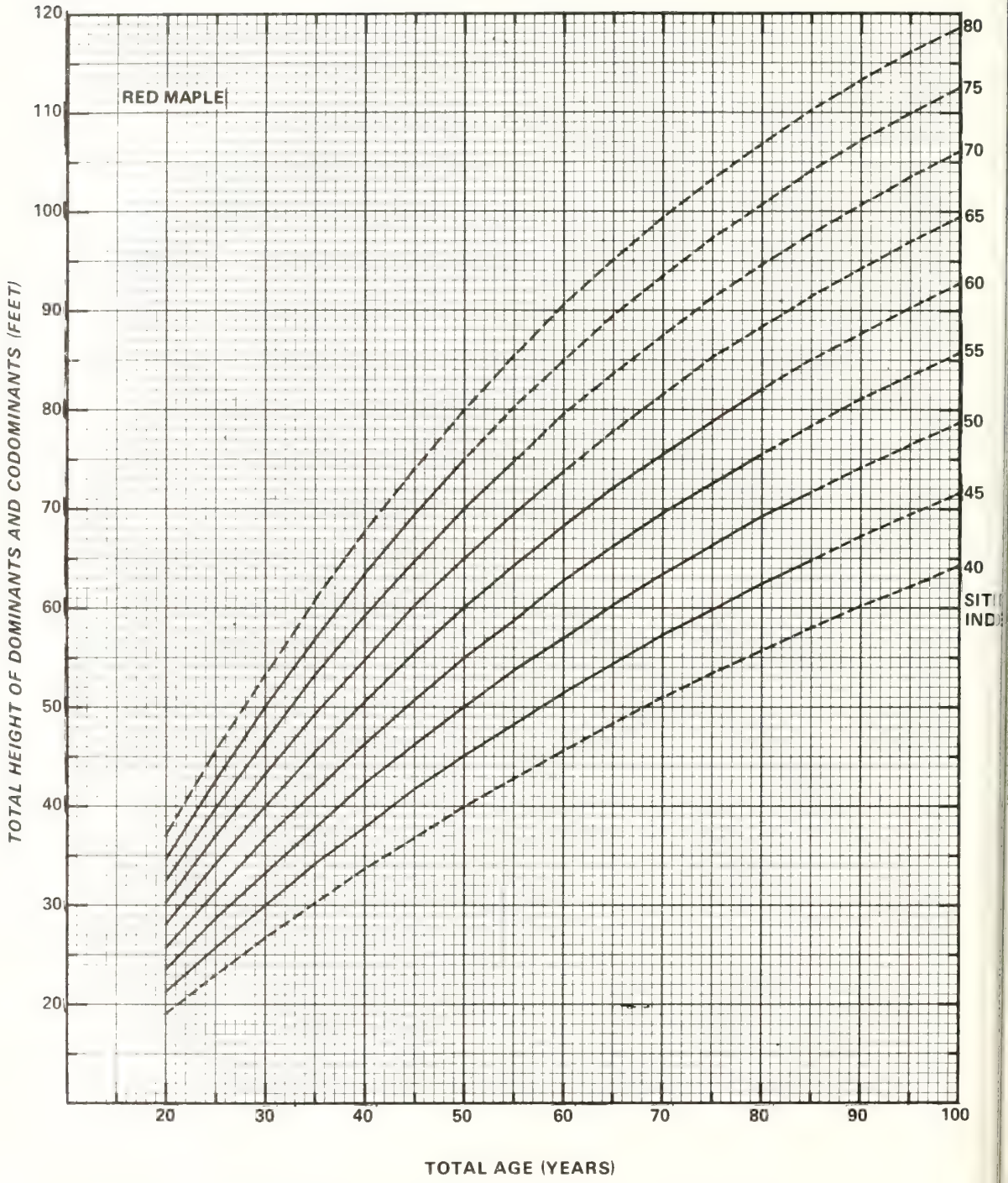

Figure 3.— *Site index curves for red maple in northern Wisconsin and Upper Michigan. These curves are based on stem analyses of 438 dominant and codominant trees growing in 114 plots. Add 4 years to breast-height age to obtain total age. Dashed lines indicate extrapolations beyond actual observed data.*

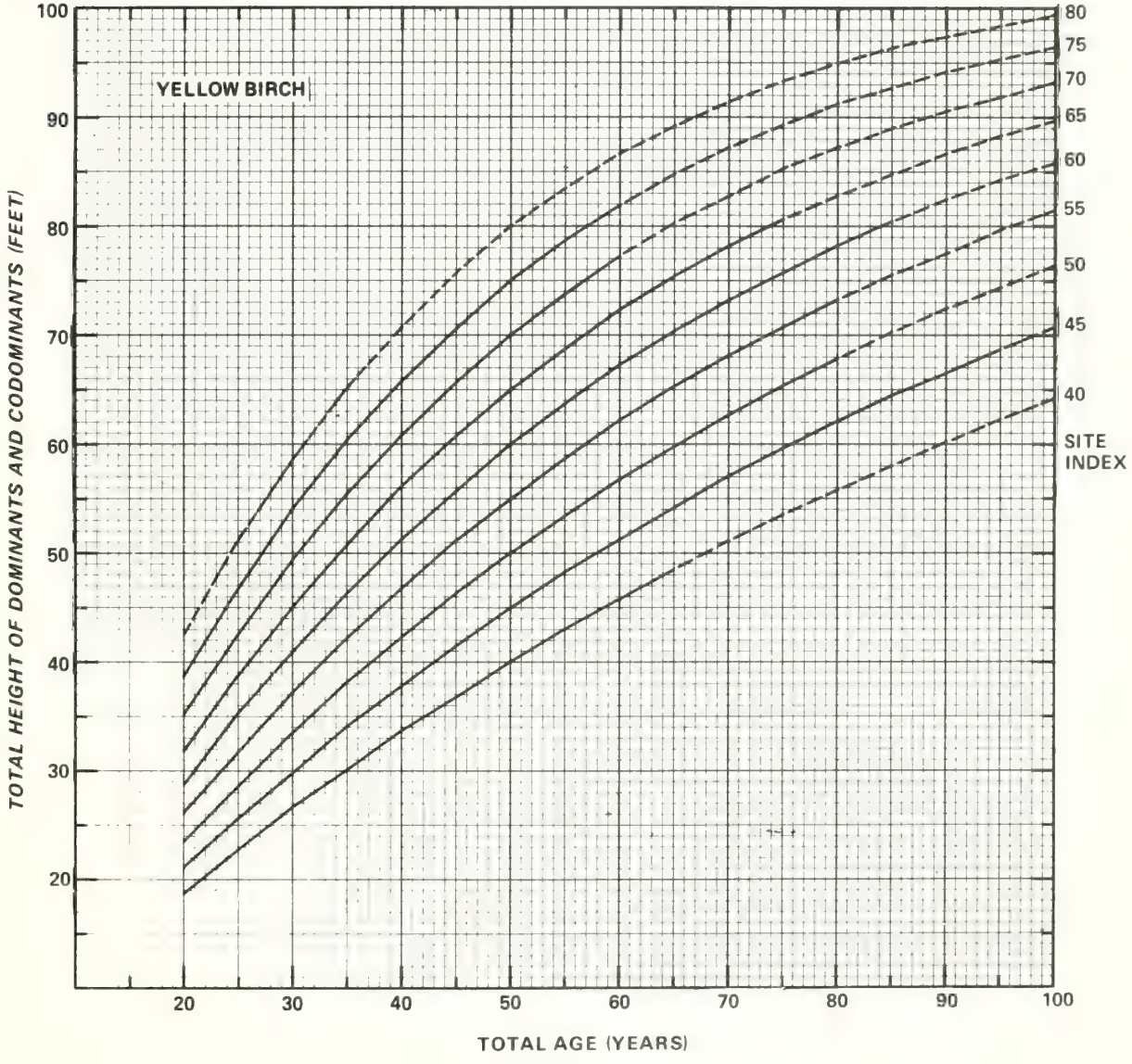

Figure 4.— *Site index curves for yellow birch in northern Wisconsin and Upper Michigan. These curves are based on stem analyses of 459 dominant and codominant trees growing in 119 plots. Add 4 years to breast-height age to obtain total age. Dashed lines indicate extrapolations beyond actual observed data.*

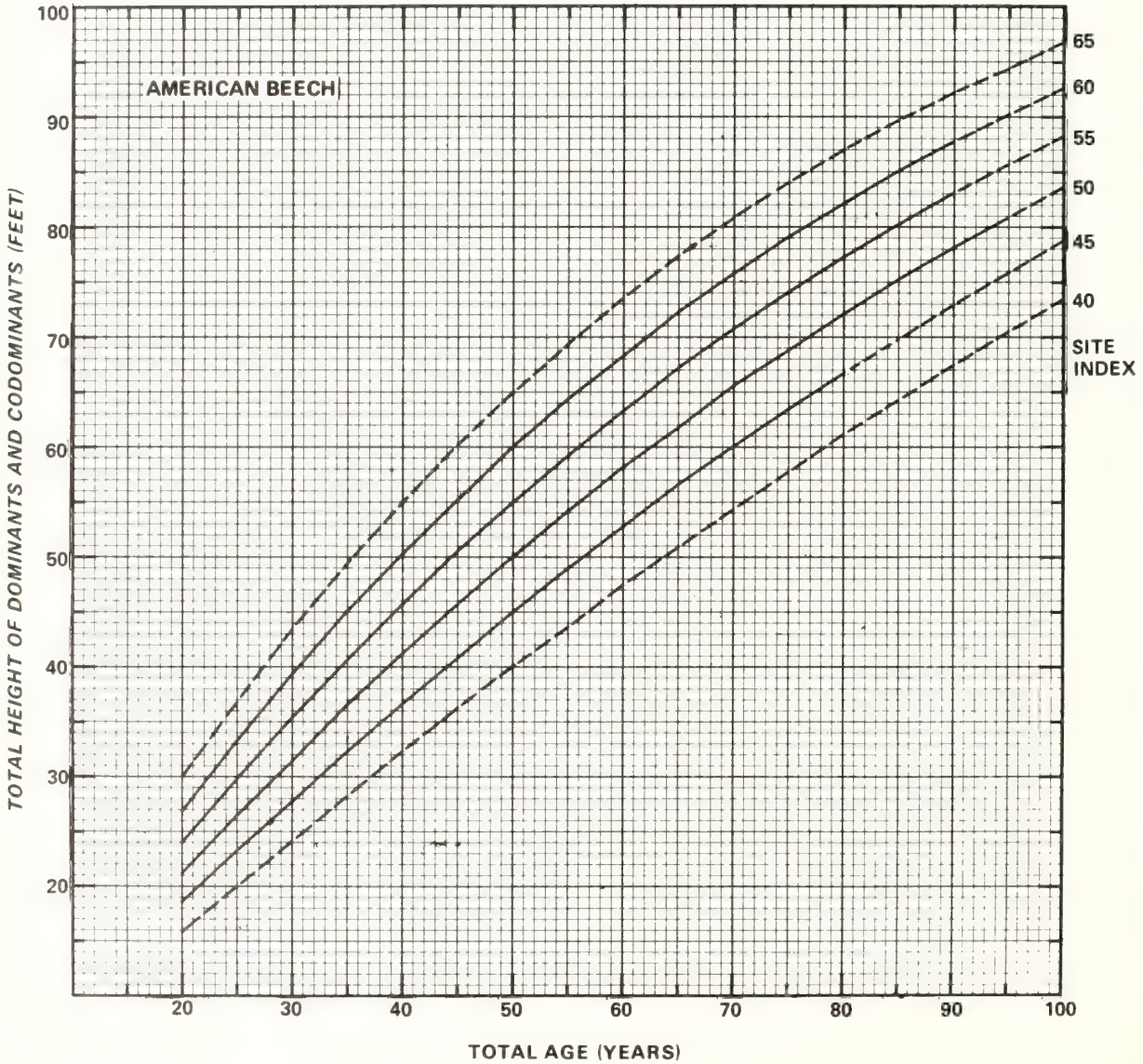

Figure 5.—*Site index curves for American beech in northern Wisconsin and Upper Michigan. These curves are based on stem analyses of 70 dominant and codominant trees growing in 19 plots. Add 4 years to breast-height age to obtain total age. Dashed lines indicate extrapolations beyond actual observed data.*

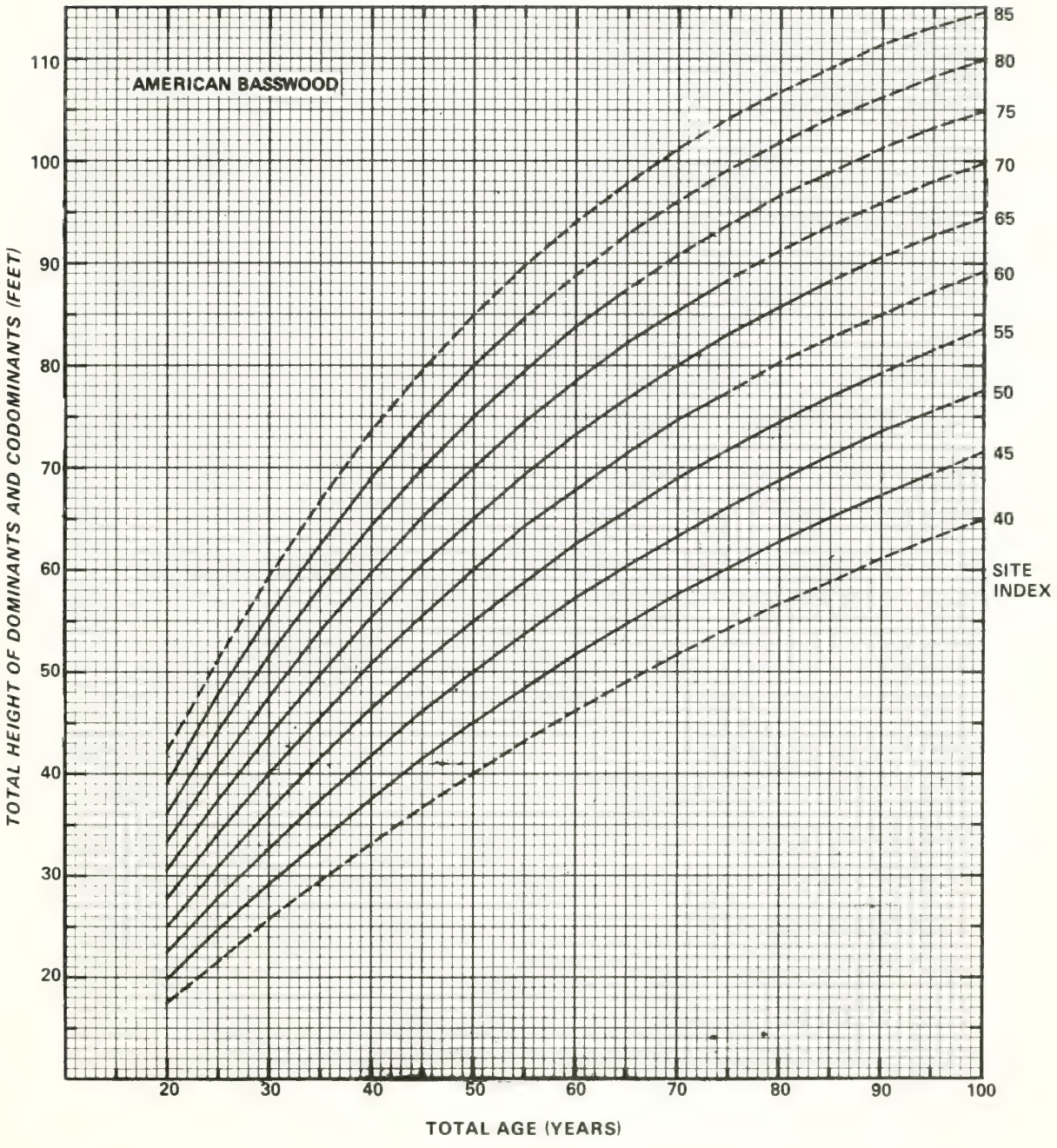

Figure 6.—*Site index curves for American basswood in northern Wisconsin and Upper Michigan. These curves are based on stem analyses of 483 dominant and codominant trees growing in 122 plots. Add 4 years to breast-height age to obtain total age. Dashed lines indicate extrapolations beyond actual observed data.*

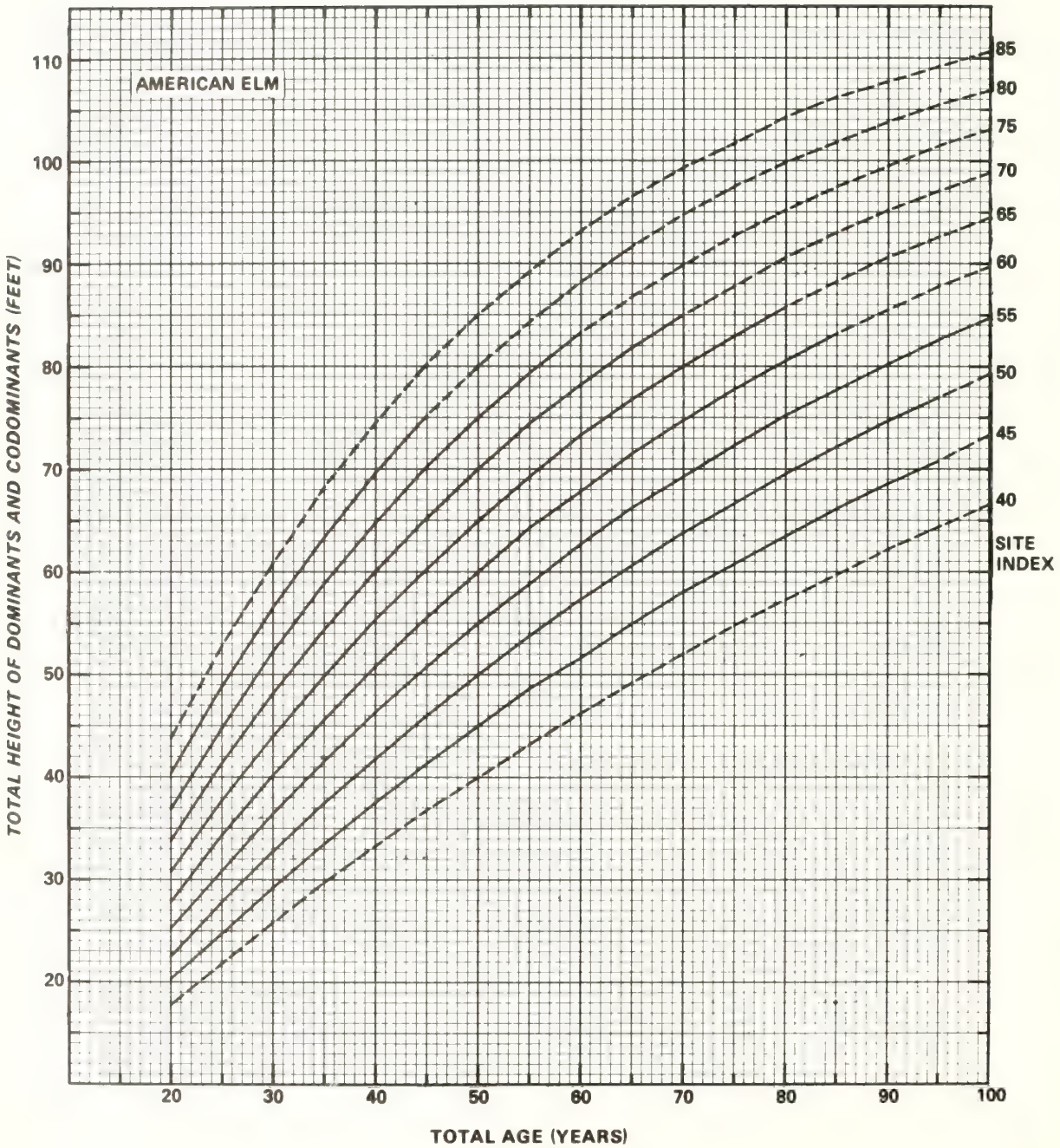

Figure 7.—*Site index curves for American elm in northern Wisconsin and Upper Michigan. These curves are based on stem analyses of 416 dominant and codominant trees growing in 109 plots. Add 4 years to breast-height age to obtain total age. Dashed lines indicate extrapolations beyond actual observed data.*

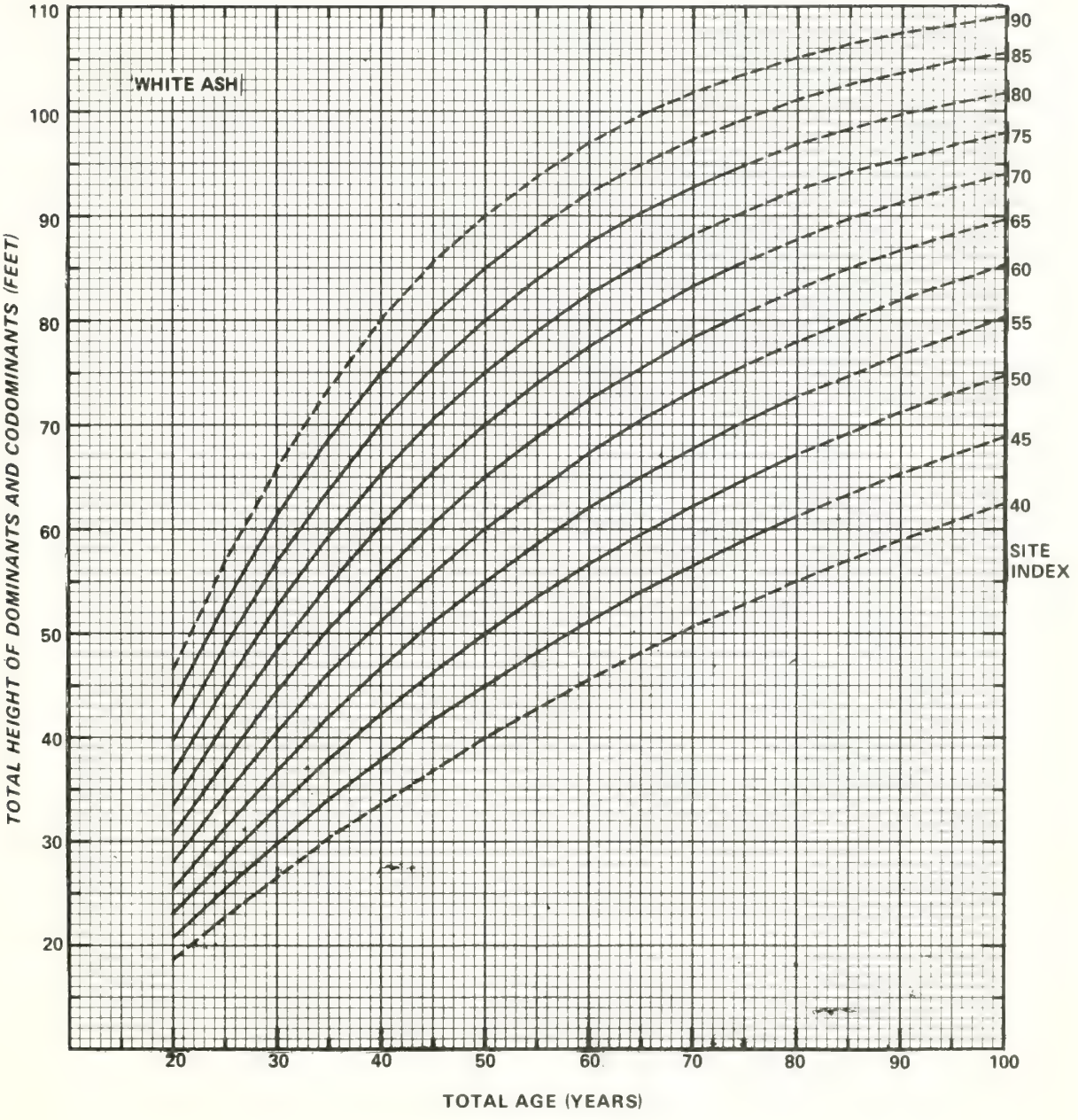

Figure 8.—*Site index curves for white ash in northern Wisconsin and Upper Michigan. These curves are based on stem analyses of 275 dominant and codominant trees growing in 73 plots. Add 4 years to breast-height age to obtain total age. Dashed lines indicate extrapolations beyond actual observed data.*

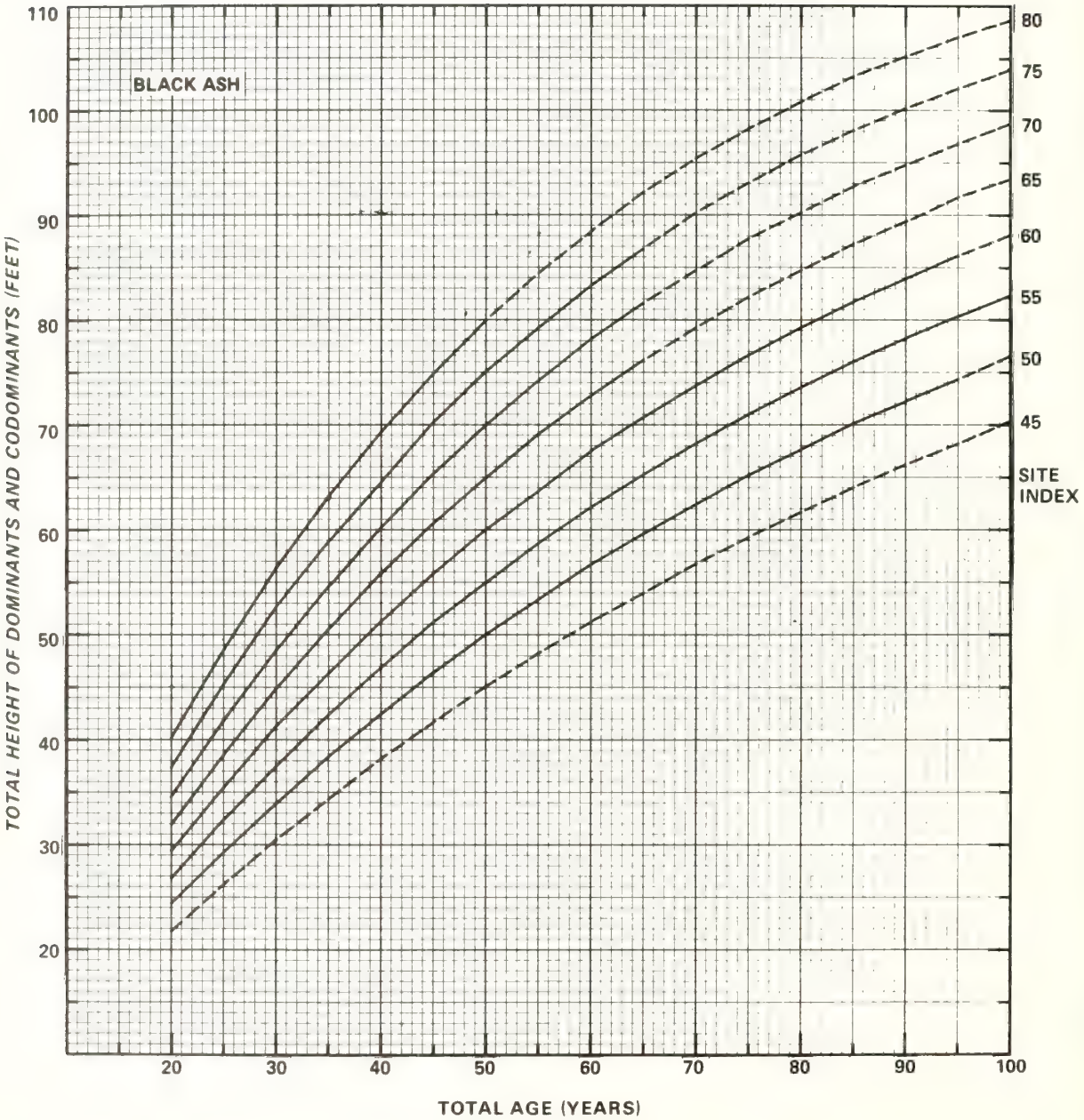

Figure 9.—*Site index curves for black ash in northern Wisconsin and Upper Michigan. These curves are based on stem analyses of 143 dominant and codominant trees growing in 39 plots. Add 4 years to breast-height age to obtain total age. Dashed lines indicate extrapolations beyond actual observed data.*

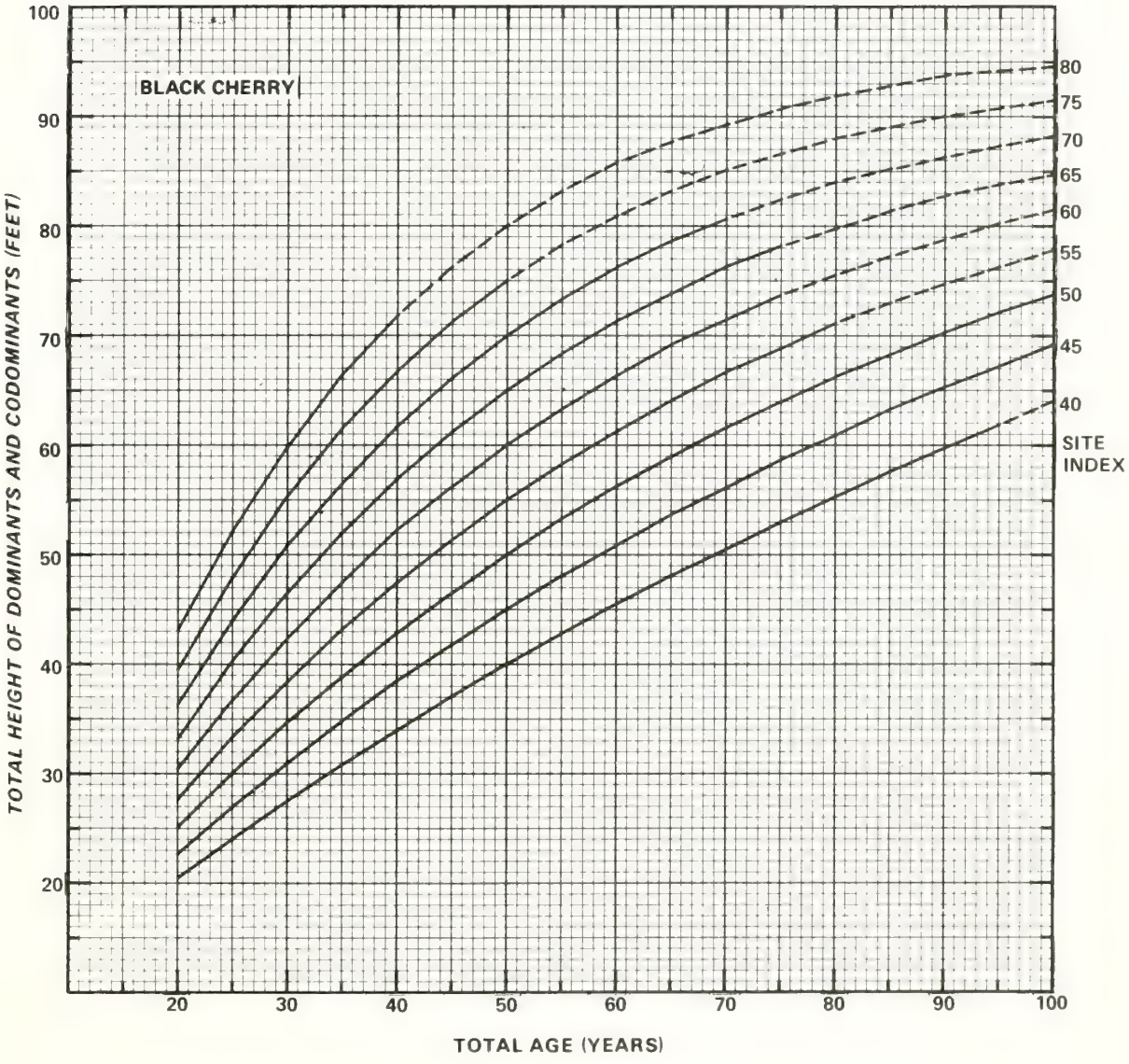

Figure 10.—*Site index curves for black cherry in northern Wisconsin and Upper Michigan. These curves are based on stem analyses of 126 dominant and codominant trees growing in 42 plots. Add 4 years to breast-height age to obtain total age. Dashed lines indicate extrapolations beyond actual observed data.*

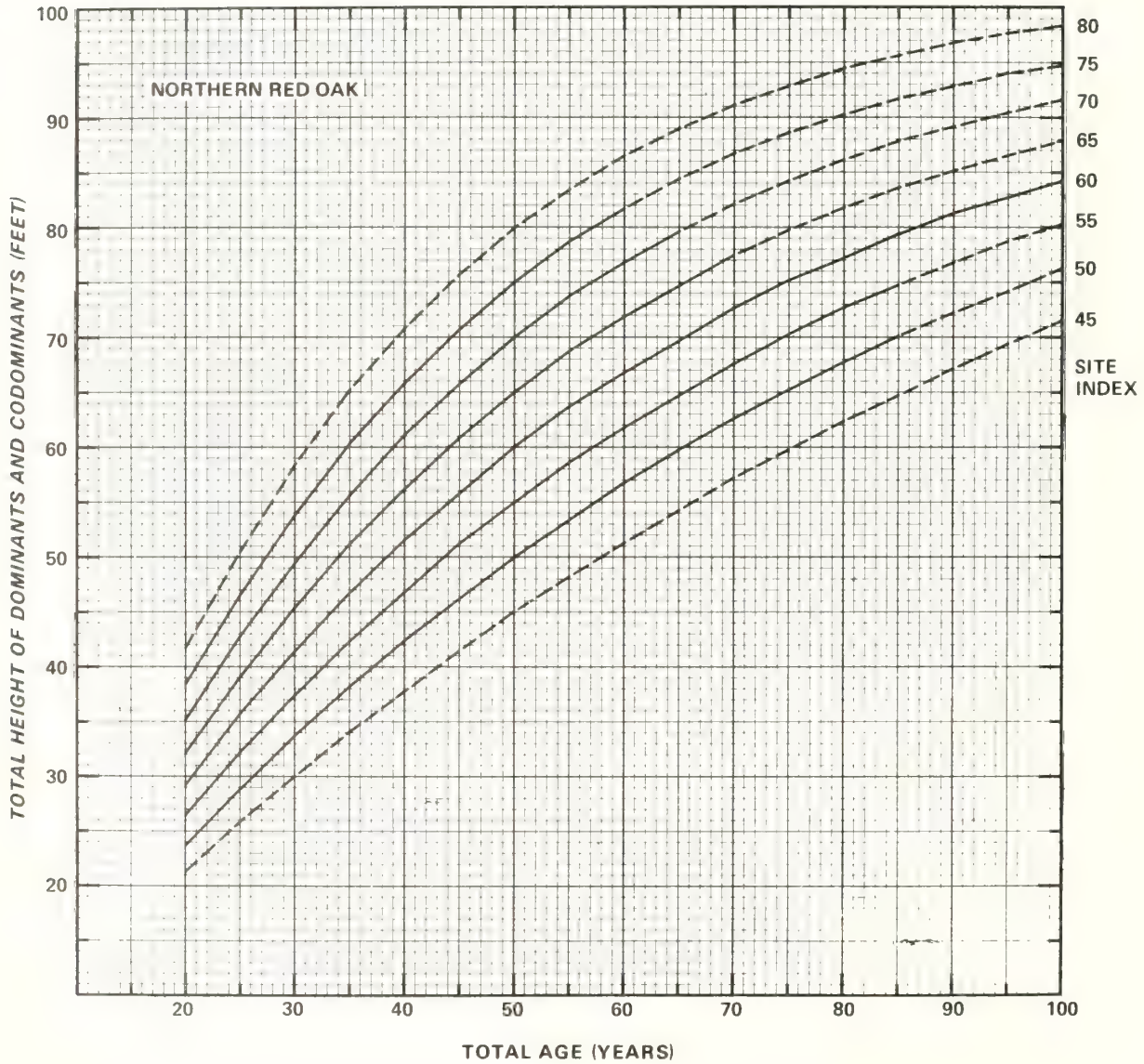

Figure 11.—*Site index curves for northern red oak in northern Wisconsin and Upper Michigan. These curves are based on stem analyses of 136 dominant and codominant trees growing in 37 plots. Add 4 years to breast-height age to obtain total age. Dashed lines indicate extrapolations beyond actual observed data.*

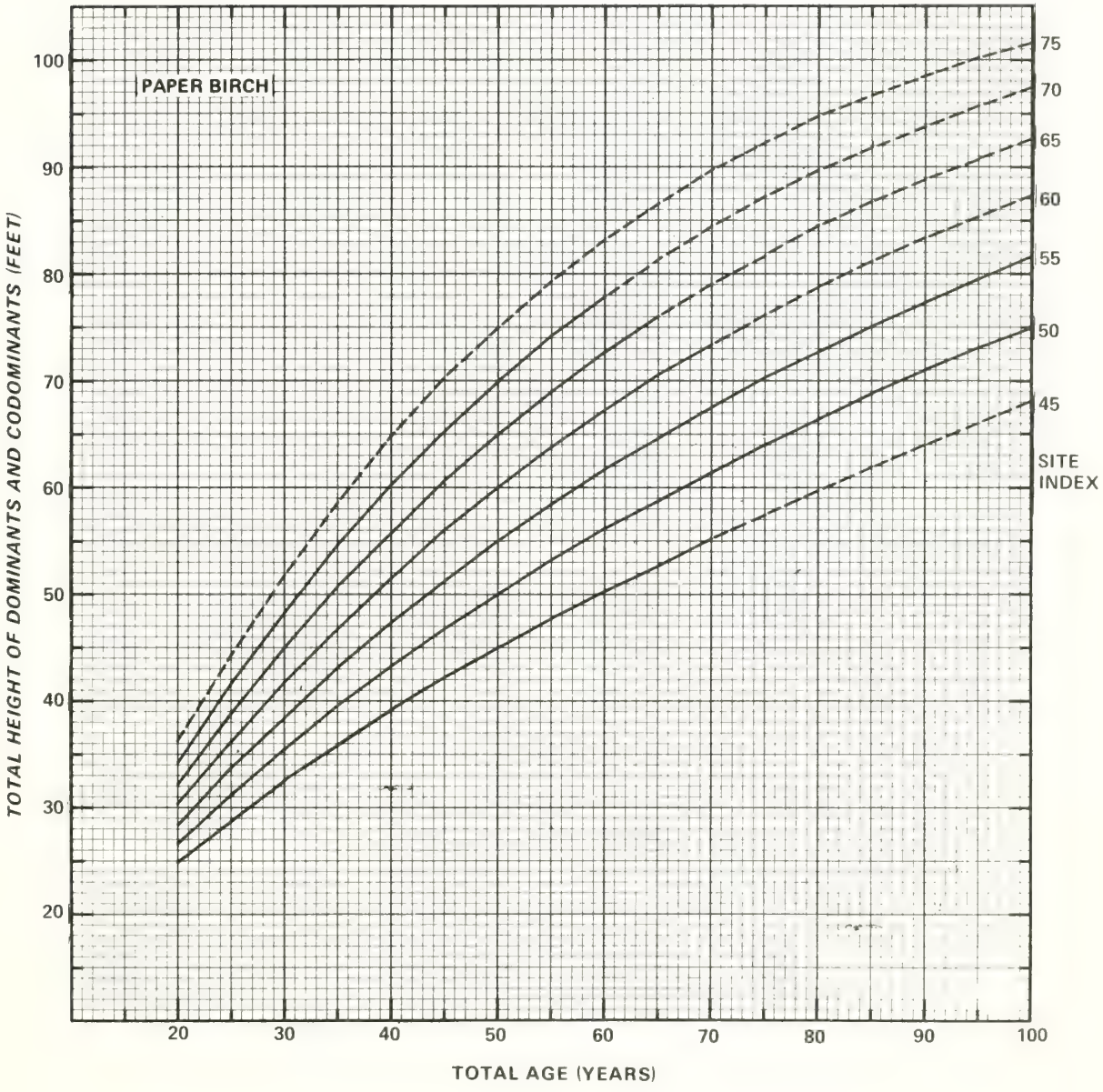

Figure 12.—*Site index curves for paper birch in northern Wisconsin and Upper Michigan. These curves are based on stem analyses of 93 dominant and codominant trees growing in 30 plots. Add 4 years to breast-height age to obtain total age. Dashed lines indicate extrapolations beyond actual observed data.*

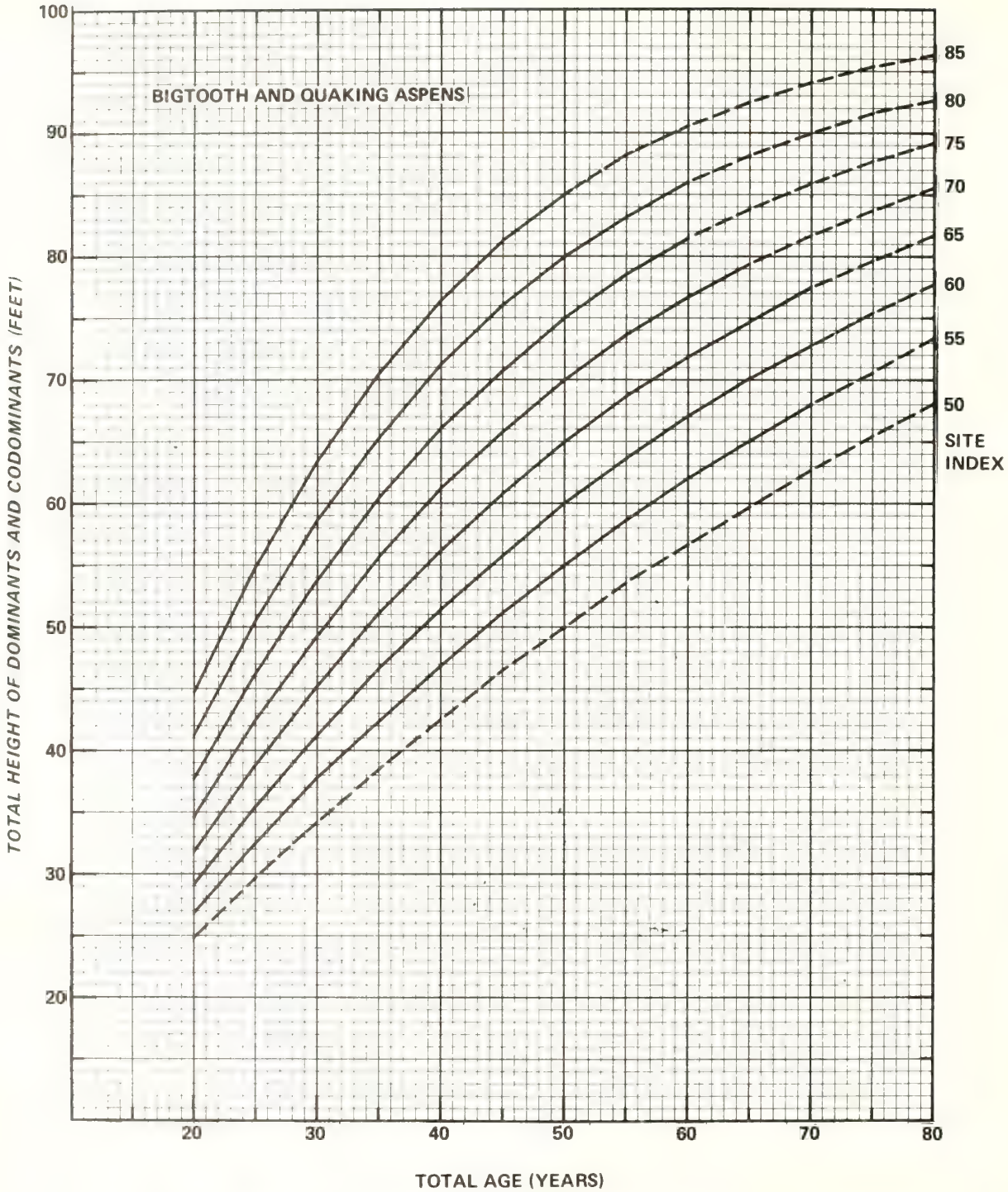

Figure 13.—*Site index curves for bigtooth and quaking aspens in northern Wisconsin and Upper Michigan. These curves are based on stem analyses of 42 dominant and codominant trees growing in 13 plots. Add 4 years to breast-height age to obtain total age. Dashed lines indicate extrapolations beyond actual observed data.*

DISCUSSION

One important finding was that height growth tterns differed for each of the species found in en-aged second growth northern hardwood ests. Shapes of height growth curves are ilar for most species in early years even though tain species such as basswood, elm, and the ies have more rapid early height growth. But er 50 years, differences in shapes of curves ween species are particularly evident for trees wing on medium and good sites. For example, low birch and black cherry have marked wing of height growth in later years on good d medium sites. In contrast, red maple and erican beech maintain height growth better in er years than do other species. Because of these ferent patterns of later height growth separate e index curves are presented for each of the rdwood species (figs. 2-13).

Another important finding was that for the most ecies the shape of the height growth curves fer (are polymorphic) for different levels of site ality. Trees on poor sites grow slowly through- their lives. In contrast, trees on good sites ve a surge of rapid early height growth followed a pronounced slowing of height growth after 50 rs.

A third finding was that for most species the e curves I computed differed from other blished site index curves (Carmean 1978). wever, most of these earlier curves either are er harmonized curves not based on stem alysis methods or they are from regions other n the Lake States.

HOW TO USE THE SITE INDEX CURVES

. Divide the area for which site estimates are eded into mappable units having similar ography, soil, and site quality. These units y be only a few acres in size for certain research dies where precise site quality estimations are eded, or they may be much larger for certain ber management units where less precise site ality estimations are needed.

. Locate well-stocked even-aged stands in h unit. Because estimates of site index are more dependable when using trees that are close to index age, these stands should be at least 20 years old and preferably should not be younger than 35 or older than 65 years of age.

3. Select at least three or four well-formed dominant and codominant trees in each stand that have been free growing and uninjured throughout their lives. The number of trees selected depends upon the desired precision of the site index estimates. This precision depends on the variability of the site index estimates among the site trees and also on the variability of the soil and topographic conditions within the mapping unit.

4. Measure total height and take an increment boring at breast height (4.5 feet) to estimate age for each site tree. Reject trees that have narrow annual rings in early years because this indicates early suppression in height growth; also reject trees that are 10 or more years older or younger than the main stand.

Annual rings are easily counted for ring-porous species such as the ashes and red oak. In contrast, annual rings are difficult to count for diffuse-porous species such as the maples, birches, basswood, beech, and the aspens. For these species annual rings are more prominent if increment cores are radially-shaved, moistened, and examined under magnification and strong light. When more accurate age and height estimates are desired, fell several dominant and codominant trees, measure total tree height, then cut a disk at dbh for use in making ring counts. Annual rings on the disks are prominent under magnification and strong light when radial portions of the disk are smoothed using a router, or a high speed electric drill or planer.

5. Use height and total age estimates with the appropriate site index curves (figs. 2-13) to estimate site index for each measured tree. Average the individual tree site indices to obtain a site index estimate for the stand or for the particular land unit.

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Site index curves based on stem analyses were computed for 13 species found in even-aged, second growth northern hardwood stands. These curves showed that most species had similarly-shaped height growth curves in early years, but after 50 years differences in both rate and pattern of growth between species was evident for trees growing on medium and good sites. Most species have differently-shaped height growth curves for different levels of site quality.

OXFORD: 541(774/775). KEY WORDS: Site index curves, stem analysis, polymorphic height growth.

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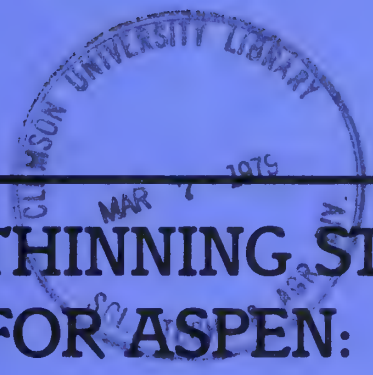

THINNING STRATEGIES FOR ASPEN: A PREDICTION MODEL

Donald A. Perala

Aspen
Birch
Conifer

Central Forest Experiment Station, Forest Service, U.S. Department of Agriculture
PROGRAM REPORT

This paper is a contribution from the Aspen-Birch-Conifer Program. The Aspen-Birch-Conifer Program is a coordinated, multi-disciplinary research effort. Its mission is to increase and integrate knowledge of the aspen-birch-conifer forests of the northern Great Lakes Region in order to better identify and evaluate resource management alternatives.

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Manuscript approved for publication October 26, 1978

1978

THINNING STRATEGIES FOR ASPEN: A PREDICTION MODEL

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Quaking aspen (*Populus tremuloides* Michx.) oc-rs extensively in the Lake States, the northeast-n United States, and the Rocky Mountains, as ll as over most of Canada. Aspen characteristi-ly regenerates from root sprouts (suckers) lowing a disturbance such as fire or timber har-st. It typically forms dense, more or less pure nds that grow rapidly and are relatively short-ed (pathological rotation ca. 40 to 70 years in e east). Yields exceed 50 tons per acre (ovendry sis) in above-ground biomass at 30 years on od, fully-stocked sites (Perala 1977). Because e diameters in dense stands are small, aspen is own primarily for fiber; it supports a large per-making industry.

Compared with pulpwood yield, aspen sawtim-r and veneer yield is low, but demand for aspen w logs has increased following a recent decision grade aspen lumber under softwood rules rinkman and Roe 1975). The present supply of pen saw logs and veneer bolts is limited to over-ture stands where cull due to decay by *Phelli-s igniarius* is high. Future sawtimber supplies ll decline as more aspen is grown on 30- to 35-ar pulpwood rotations. However, yield of wtimber and veneer bolts could be increased by termediate thinnings that would concentrate owth on select trees, and by shortening rotations minimize decay losses.

Many analyses of aspen growth are available ella 1972, Day 1958, Hubbard 1972, Schlaegel 71, 1972, Schlaegel and Ringold 1971, Sorensen 68, Steneker 1964, 1969, 1974, Steneker and rvis 1966). Most are for unthinned or once-nned stands, and are not well-suited to analyz-g aspen growth response following multiple thinnings to various stand densities. A model is needed to help prescribe economically and silvicul-turally sound thinning strategies to assure a fu-ture supply of aspen sawtimber and veneer bolts.

The model presented here is for site index 80 quaking aspen; it includes equations for stand growth in basal area, height, and sawtimber and veneer bolt volumes. Stand density in basal area and number of trees, stand age, and thinning ef-fects are the primary independent variables. The impacts of growing season variation in rooting zone soil moisture and maximum air temperature, and defoliation by forest tent caterpillar (*Malaco-soma disstria* Hubner) were also quantified.

STUDY AREA

A thinning demonstration in a uniformly dense (4,250 stems, 48 square feet basal area per acre), 13-year-old quaking aspen sucker stand was in-stalled in March 1936 on the Pike Bay Experimen-tal Forest, Minnesota (47° 20′N, 94° 30′W). The soil is a Warba very fine sandy loam with clay-loam subsoil—a good site for aspen. Elevation is 1,310 feet and topography is nearly level, with less than 2 percent slope. The climate is continental with a mean annual precipitation of 24 inches and mean July temperature of 68° F.

METHODS

Six 0.6-acre plots were thinned at three or four different times to maintain a full range of stem densities (table 1). Plots were remeasured during the dormant season at 5-year intervals over 40

Table 1.—*Summary of residual basal area and number of trees after repeated thinning in aspen*

Plot	Age at thinning (years)							
	13		23		28		33	
	Basal area	Trees per acre	Basal area	Trees per acre	Basal area	Trees per acre	Basal area	Tr per
	ft² /a		ft² /a		ft ² /a		ft ² /a	
207	30.1	1,717	58.2	1,100	[1] 76.9	[1]900	77.8	
208	25.8	1,675	64.9	1,242	[1] 81.9	[1]1,000	78.9	
210	21.2	1,216	54.2	775	58.5	558	62.4	
212	18.8	975	57.8	677	63.0	450	67.6	
211	14.2	544	53.0	383	61.3	272	63.4	
213	9.5	396	28.5	221	40.8	183	49.6	

[1]Not thinned at age 28.

years of growth. Each tree was classed as poor risk, secondary growing stock, or primary growing stock.[1] This was the ordered priority for removal in thinnings and provided the equation data for residual basal area after thinning (equation 6, table 3). Diameter of each live tree was measured at 4.5 feet (d.b.h.) with a steel diameter tape to the nearest 0.1 inch. Trees that died were not remeasured; their diameters at the beginning of the growth period were used for computing gross and mortality basal areas. Basal area was computed by $(\text{d.b.h.})^2$ summation expanded to a per-acre basis. Initially, about 50 trees per plot representing the diameter range were measured for height to the nearest foot with an Abney level. This number declined by half for the last remeasurement. Mean stand height was determined at each measurement and after each thinning by regressing measured tree height over *l*n (natural logarithm) d.b.h. and solving for the tree of mean basal area. It should be stressed that any event that increases mean stand d.b.h., such as thinning or mortality of small trees, also increases mean stand height.

Summaries of monthly climatological data (U.S. Department of Commerce 1926-1975) for May-August at an official weather station in Cass Lake, Minnesota (315°, 5.1 miles from the study) provided the variables (average temperature, average maximum temperature, and total precipitation) needed for the climatic analysis. Soil moisture was assumed to be at field capacity on May 1 and succeeding average monthly soil moistu storage values for May through August of ea year were computed according to Thornthwa and Mather (1955) using average monthly temp ature, total precipitation, and a rooting zone of feet having maximum soil moisture retention of inches.

The only natural stand disturbance was a for tent caterpillar outbreak from 1951 to 19 Yearly defoliation was estimated to average 35, and 38 percent.

Basal area growth was separated for analy into three components: gross basal area grow mortality basal area, and mortality mean d.b Gross basal area growth includes basal a growth of surviving trees plus basal area of m tality trees. Since all trees were measured, th was no ingrowth. The height growth componen the difference between mean stand height of l trees only (mortality excluded at remeasureme All growth is expressed as 5-year growth.

Scatter diagrams of dependent over indepe ent variables helped determine order of indepe ent variable input and equation form. The d were fitted using least squares techniques; t residuals about the equation were plotted agai the remaining independent variables, and a n equation term selected. This process was reit ated until no trend of residuals over any stand environmental variable was detected.

All equation terms are explained in table 2. T final four equations that describe stand grow and two equations that estimate mean sta height and basal area after thinning are given

[1]*Primary growing stock: sound, progressive, good form; secondary growing stock: either sound, progressive with poor form, or sound but regressive; poor risk: all defective and suppressed trees with poor crowns.*

Table 2.—*Explanation of independent variables, notations, units, and range of data or limitations for model inputs*

ymbol	Meaning	Units	Range (or limitations)
	Stand age at beginning of growth period	Decades	1.3-4.8 (1.0-5.5)
	Stand age at end of growth period	Decades	(1.5-6.0)
h	Stand age at beginning of growth period immediately following thinning	Decades	(1.0-3.5; enter "0" for all other growth periods)
d	Time since peak defoliation, including time in current growth period	Decades	(cannot exceed 1.8; "0" otherwise)
d^y	Time since peak defoliation, including time in current growth period, to the power of y (y = 1 for growth period following thinning, $y = (Td)^2$ for other growth periods)	Decades	(Td cannot exceed 1.0; "0" otherwise)
	Stand live basal area at begining of growth period	ft^2/acre	9.5-121.9
,	Stand live basal area before thinning	ft^2/acre	(<150)
	Stand number of trees at beginning of growth period	1,000/acre	0.140-1.717
,	Stand number of trees before thinning	1,000/acre	(<6.000)
h	Stand number of trees after thinning	1,000/acre	(0.090-2.000)
	Mean stand d.b.h. (of tree of mean basal area at beginning of growth period)	Inches	1.68-11.18
	Mean stand d.b.h. at end of growth period	Inches	(>1.5)
	Mean stand height (of tree of mean basal area at beginning of growth period)	Feet	24.1-80.7
(/nF), nM)/F	Five-year mean interaction terms of mean monthly (jn = June, jy = July) soil moisture storage according to Thornthwaite and Mather (1955) and maximum air temperature. Computed as: $M(/nF) = \frac{\sum_{1}^{5} (M)(/nF)}{5}$ where means are for current growth period, and $(/nM)/F = \frac{\sum_{1}^{5} (/nM)/F}{5}$ where June and July means are for 5-year periods ending 3 and 9 years earlier, respectively, than last year of current growth period.	$F = \frac{F° - 50}{10}$, M = inches	June: 10.63-11.66, July: 11.91-13.74 for M(/nF); June: 1.022-1.190, July: 0.672-0.845 for (/nM)/F.
	Mean percent defoliation during a 5-year growth period	Percent	1-26("1" for nonepidemic growth periods)
p, e	Base of natural logarithms	——	——
	Natural logarithms	——	——

Table 3.—*Aspen growth and stand characteristic equations*

Dependent variable	Independent variables[1]	R^2	$\bar{Y}$	[2]Sy.x	[3]N	Eq.
Bg (5-year gross basal area growth, including mortality, ft²/acre)	$B \cdot \exp \{b_o + b_1 (/nT + 2.3)^{-1} + b_2 /nB + b_3 NT(/nB) + b_4 [NT(/nB)]^{-1} + b_5 [M(/nF)]_{jn} + b_6 [M(/nF)]_{jy} + b_7 /nP\}$	0.99	22.6	6.8	48	(1)
Bm (5-year mortality basal area, ft²/acre)	$-1 + \exp \{b_o + b_1 (T - 1.73)^2 + b_2 B + b_3 B^{T/D} + b_4 [(/nM)/F]_{jn} + b_5 [(/nM)/F]_{jy} + b_6 /n\ Tth + b_7 [.097^{eTd} \cdot (e^{Td})^{7.0}]\}$	.76	3.4	54.8	48	(2)
Dm (quadratic mean d.b.h. of mortality, inches)	$\exp \{b_o + b_1 e^{-T} + b_2 /n\ Tth + b_3 /nD + b_4 /n\ Bm + b_5 /n (1 + Td^y)\}$	.95	4.1	12.0	45	(3)
ΔH (5-year mean stand height growth, feet. Based on tree of mean basal area)	$H \cdot \{\exp [b_o + b_1 /n \frac{/n(D_1+1)^{T1}}{/n(D+1)^T} + b_2 P]\} - H$	.88	6.2	22.7	48	(4)
H (mean height, feet, of stand or stand component such as mortality or removals)	$\exp \{b_o + b_1 /nT + b_2 /n [/n (D+1)^T]\}$	.99	51.9	2.7	54	(5)
B_{th} (stand basal area after thinning, ft²/acre)	$\exp \{/nB_o + b_o + b_1 [/n (\frac{100\ Nth}{N_o})]\}$	.99	36.6	11.1	50	(6)

[1]Coefficients are given in table 4.

[2]Sy.x is converted from the logarithmic form to the arithmetic form according to Baskerville (1972) and is expressed as a percent of arithmetic mean Y.

[3]Number of observations.

table 3; equation coefficients are in table 4. The growth equations were checked by comparing predicted values with values observed on other aspen thinning studies on the Pike Bay Forest and elsewhere in northern Minnesota (table 7, Appendix). No independent data were available for testing equation 6 (table 3).

The model was then used to predict how a number of thinning strategies, varying or constant climate, and defoliation would affect stand growth and development. Data from a sucker stand growing nearby on the same soil were used for prethinning densities at age 10. For comparison, Perala's (1973) equations were used to estimate basal area growth and stem survival in unthinned stands aged 10 to 20, and Schlaegel's (1971) equations were used for stands aged 20 to 60.

Volumes were determined from the following stand equations developed by Schlaegel (1974, 1975):

$$V_{bw} = \exp.(.996\ /n - BH - .854) \quad (7)$$

$$V_6 = V_{bw} [1.056 - 6.476\ (.735^{D})] \quad (8)$$

$$V_8 = V_{bw} [.889 - 33.261\ (.653^{D})] \quad (9)[2]$$

where:

V_{bw} = total bolewood volume cubic feet/acre, excluding 6-inch stump,

[2]*Schlaegel developed but did not publish equation (9).*

Table 4.—*Equation ceofficients and significance (in parentheses) as determined by t-test*

uation[1]	[2]b_0	b_1	b_2	b_3	b_4	b_5	b_6	b_7
)	−4.7159	+6.3111	−0.8921	−0.03946	−1.186	+0.1887	+0.3191	−0.2419
	(.001)	(.001)	(.001)	(.001)	(.001)	(.001)	(.001)	(.001)
)	−2.432	+.0593	+.00925	+.067	+4.38	−3.22	−.235	+.353
	(.3)	(.4)	(.3)	(.01)	(.02)	(.2)	(.2)	(.05)
)	−1.1635	+3.421	+.1506	+1.372	+.0608	−.2094		
	(.01)	(.01)	(.01)	(.001)	(.05)	(.1)		
)	+.0025	+.513	−.0025					
	(.6)	(.001)	(.001)					
)	+3.084	−.17	+.618					
	(.001)	(.05)	(.001)					
)	−3.324	+2.176						
	(.001)	(.001)						

o use equations (1), (2), and (4) with average climate and no defoliation assumptions, ignore the climate and defoliation terms and bsititute these values for b_0:

Equation	b_0	Ignored terms
(1)	+5.9369	b_5, b_6, b_7
(2)	−0.1814	b_4, b_5, b_7
(4)	+0.000	b_2

onstant includes correction for logarithmic bias (Baskerville 1972).

V_6 = bolewood volume to a 6-inch top (i.b.), cubic feet/acre,

V_8 = bolewood volume to an 8-inch top (i.b.), cubic feet/acre,

BH = stand basal area (B, square feet/acre) x mean stand height (H,feet), and

D = mean stand d.b.h., inches.

ote that Schlaegel's 7-inch and 9-inch outside rk ratio estimators are used to estimate to inside rk industry standards. Since double-bark thickss of aspen is approximately 0.5 inch, these estiates are somewhat conservative. All volumes e gross volumes without deduction for defect.

A 40-year climate "loop" using the same 5-year ean climate record sequence observed in this udy was used to simulate growth response at fferent ages to varying climate. The "loop" was lvanced 5 years at the start of each of eight 40ar growth simulations. The varying climate put was followed in sequence, rather than ranmly, to mimic its cyclic nature.

The effect of defoliation on aspen growth was mulated specifying constant average climate. is simulation specified 3 years of defoliation ginning the first year after thinning at age 30 and peaking at 38 percent— similar to what was observed in this study.

RESULTS AND DISCUSSION

Thinning

Most of the stand variables in this analysis are those commonly used in forest growth studies: basal area, number of trees, stand age, and mean stand diameter. Mean stand height (height of tree of mean basal area) is usually not used in growth studies although it is more accurate than dominant height when used in the combined variable, BH (see equation (7)), to estimate stand yields (Schlaegel 1974). Mean stand height, however, requires a large number of observations to develop height/diameter curves, compared with the fewer observations required for dominants and codominants alone. Mean stand height is a more precise integrator of the effects of defoliation and climate on height growth because, as will be pointed out later, these stresses are more pronounced in the lower dominance classes.

Variable forms used here (e.g., logarithms, polynomials) are common to growth studies. Two exceptions are the combined variables incorporating number of trees (N), stand age (T), and stand basal

area (B). In equation (1) (table 3), NT(lnB) indicates that gross basal area growth (ΔBg) is maximized with optimum interactions of basal area and number of trees at a given age (climate and defoliation effects excluded). This is biologically sound, since stand growth is limited at low densities by incomplete utilization of the site and at high densities by overcrowding. The combined variable $B^{T/D}$ in equation (2) (table 3) says that mortality basal area (Bm) increases with decreasing mean stand d.b.h. (D) at a given age. This can be interpreted as follows: for stands of the same age and basal area, but with decreasing mean stand d.b.h., there must be a greater number of trees (on a given site) and therefore more intense competition, more trees under stress, and more trees dying.

Although thinning did affect ΔBg indirectly by changing the number of stems, basal area, and their interactions, thinning did not directly affect ΔBg. In contrast, thinning *per se* slightly lowered Bm, presumably because risk trees were removed. However, thinning increased mean d.b.h. of mortality, probably by exposing larger trees to sunscald or by providing favorable conditions for insects or pathogens. Both of these effects lasted only through the first 5-year growth period after thinning, and neither importantly influenced stand growth.

The first simulations identified thinning densities that would maximize volumes of saw logs and veneer bolts at the regeneration cut and before the onset of pathological rotation, usually 50 years. These simulations specified no defoliation and average climate. The strategies included thinning to 2,000, 1,500, 1,000, 750, and 500 stems per acre initially at age 10, with other thinnings to one-half initial stem density at age 20 and one-fourth initial stem density at age 30. At age 50, figure 1a shows that 1,500 and 1,000 stems initially were optimum for basal area growth. Of course, mean stand diameter decreased with increased stocking (fig. 1b). Because merchantable volume is a direct function of stand basal area and mean stand d.b.h. (equations 7-9), 750 stems per acre proved to be the optimum initial density for sawtimber (fig. 1c) and veneer (fig. 1d), followed closely by the 1,000 and 500 initial densities. There is little practical difference over the range of 500 to 1,000 stems initial density in veneer bolt volumes; the 500 density may be preferred because there are fewer, larger stems to handle. Also, milling efficiency is increased with fewer but larger, higher quality bolts and less waste in cores. It is undesirable to thin to densities lower than 500 stems because the site is underutilized and natural pruning of aspen tends to suffer.

After much trial, two other useful thinning strategies emerged; an initial thinning at age 10 to 550 stems per acre with (a) no further thinning or (b) a single repeat thinning to 200 stems per acre at age 30. The single thinning increased merchantable volume but the two-thinning strategy was a great improvement, producing nearly as much 6- and 8-inch material as the highest yield strategies (fig. 2).

Finally, a single commercial thinning to 240 trees per acre at age 30 or 35 was simulated. Compared with no thinning, this thinning improved volume of sawtimber, especially veneer bolts, at age 50 (fig. 2). It must be cautioned that thinnings so late in the rotation risk increased mortality from sunscald, which is not accounted for by the model (see Appendix). Therefore these simulations probably overestimate net thinning response.

Other thinning strategies were simulated, including very light thinnings at 5-year intervals but these gave at best only slight increases in sawtimber or veneer above the best strategies already described.

The model shows that thinnings can increase the rotation yield of *total* bolewood by as much as 40 percent compared with no thinning (table 5). The 1,000/500/250 thinning strategy was the most efficient in this regard because it salvages mortality (table 5) and maintains the stand closest to optimum density over a greater proportion of the rotation.

The 550/200 stems at ages 10/30 strategy seems most advantageous, since only two thinnings are needed to yield nearly maximum sawtimber, veneer, and total bolewood. However, trees in stands grown with this strategy will average almost 2 inches smaller in d.b.h. at age 50 than those in stands also thinned at age 20. If a larger product is desired, a three-thinning strategy (500/250/125 stems at ages 10/20/30, fig. 1) should be considered.

Table 5.—*Simulated bolewood yield of thinnings and crop trees, and gross production over a 50-year rotation (see figs. 1 and 2 for additional stand structure information)*

Thinning strategy		Mean d.b.h. thinnings	Volume removed					Mortality volume[1,5]	Total gross production[1,5]
			Thinnings[1]	Regeneration cut			Total[1]		
				[2]6-in	[3]6-in	[4]8-in			
trees/acre	*age*	*inches*	*cunits per acre*						
2000/1000/500	10/20/30	1.2/2.6/4.0	1.5/4.9/7.1	16.4	33.5	11.2	63.4	9.9	73.3
1500/ 750/375	10/20/30	1.2/3.0/4.6	2.0/5.2/8.5	11.5	43.3	26.9	70.5	8.2	78.7
1000/ 500/250	10/20/30	1.3/3.5/5.6	2.6/5.1/8.3	5.2	51.8	40.5	73.0	6.5	79.5
750/ 375/188	10/20/30	1.3/3.8/6.2	3.0/4.7/8.0	2.4	52.6	43.2	70.7	5.4	76.1
500/ 250/125	10/20/30	1.4/4.1/6.7	3.5/3.7/6.7	0.5	46.1	38.7	60.5	3.7	64.2
550/200	10/30	1.4/5.7	3.4/11.9	3.3	49.8	40.3	68.4	5.4	73.8
550	10	1.4	3.4	15.5	44.7	23.3	63.6	11.9	75.5
240	30	4.3	15.8	6.4	38.3	27.7	60.5	3.7	64.2
240	35	4.9	15.9	7.2	36.0	24.9	59.1	3.2	62.3
Unthinned		—	—	19.6	31.7	4.6	51.3	—	—

[1]Total bolewood, 6-inch stump to tip of tree.
[2]Total bolewood minus yield to 6-inch top.
[3]Total sawtimber and veneer volume.
[4]Veneer bolt volume.
[5]Excludes mortality prior to thinning (mortality is not modeled in unthinned stands).

Climate

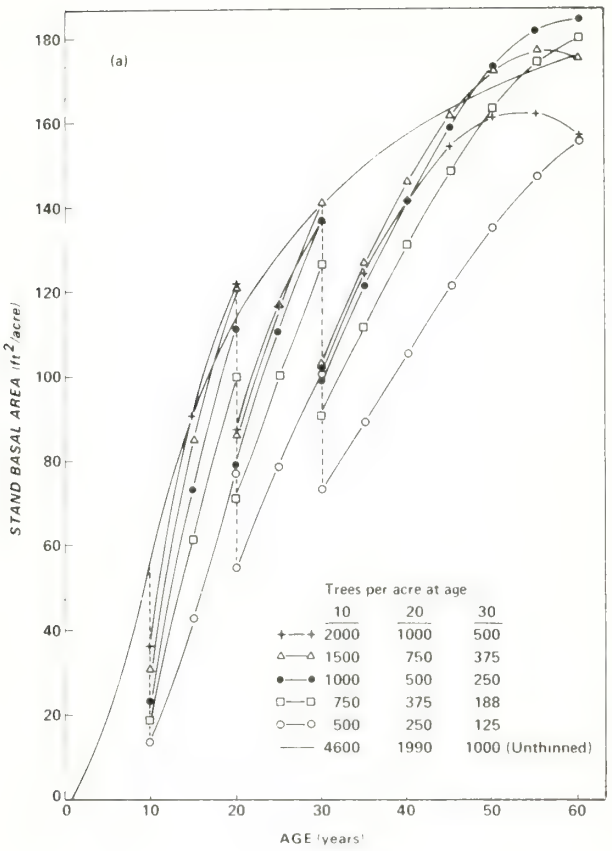
Tree growth is limited more often by internal water deficit than by any other factor (Kramer and Kozlowski 1960). Variations in radial growth with climatic variation are well-documented (Fritts 1976) and are particularly useful for archaeological dating and reconstructing past climate.

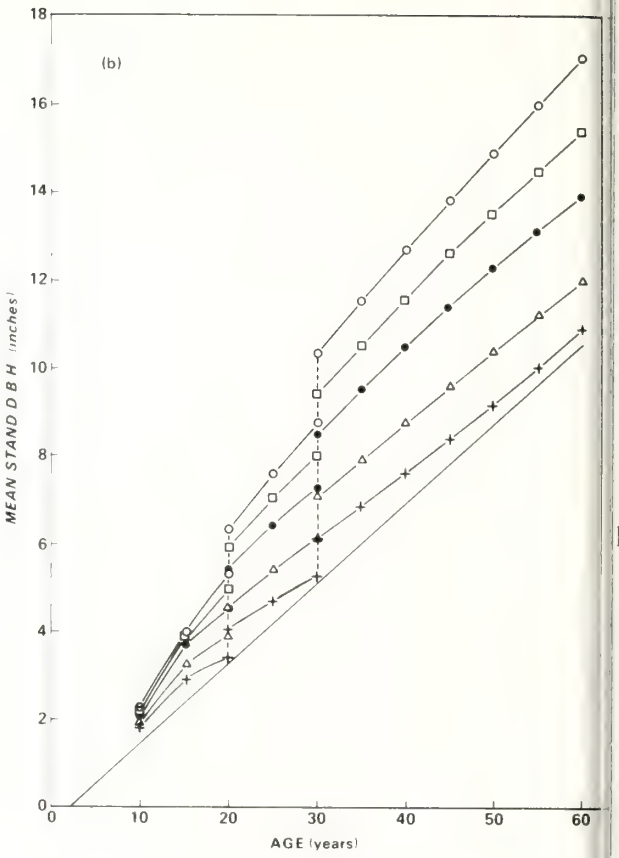
Several researchers have shown that radial tree growth responds directly to variation in growing season soil moisture, air temperature, or both (e.g., Bassett 1964, 1966, Fraser 1962, Fritts 1974, Phares and Rogers 1968). Variations in daily maximum temperature, relative humidity, percent of possible sunshine, and wind velocity are also important, but to a lesser degree (Fraser 1956, Fritts 1958, 1966, 1974). Variations in annual height growth with climatic variation are less well-documented. However, temperature and soil moisture (Cantiani 1967, Cremer 1975, Schmidt 1969, Yu 1964) have been correlated with height growth; temperature is apparently more important in the spring and soil moisture more important in the summer.

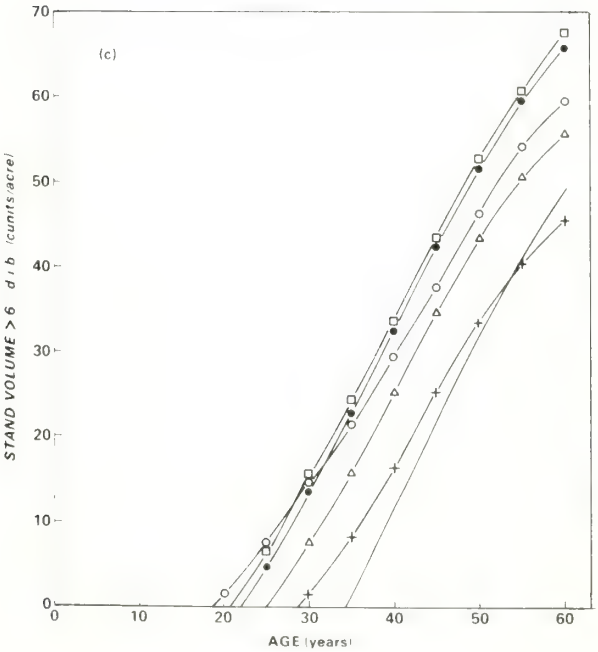
Quaking aspen has relatively inefficient stomatal control of transpiration (Tobiessen and Kana 1974). It is not surprising, then, that the climatic variables governing evapotranspiration and soil moisture availability—and therefore the water balance—measurably alter aspen growth. The importance of soil moisture is reflected in the rapid improvement of aspen site index with relatively small increases in soil moisture (Stoeckeler 1960, Graham *et al.* 1963).

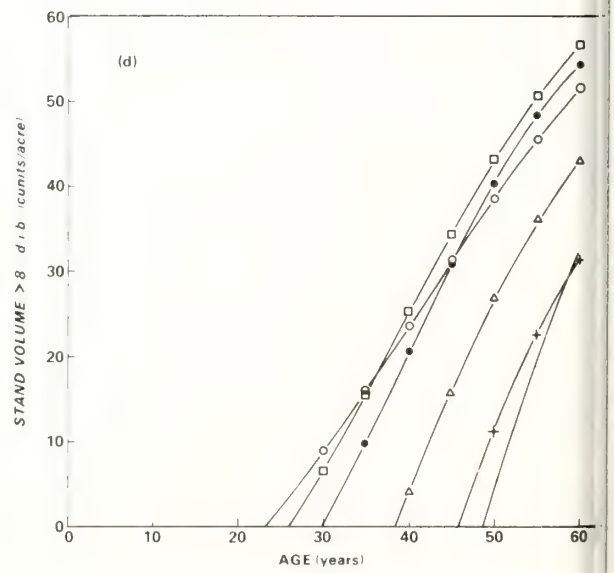
Climatic variation also affects forest growth by inducing stress that kills trees directly or weakens their resistance to injurious biological agents. In aspen, *Armillaria mellea* causes root rot (Schmitz and Jackson 1927) that may be favored by a series of dry summers (Leaphart 1963). Hypoxylon canker, caused by *Hypoxylon mammatum*, is a common disease in aspen estimated to kill 1 to 2 percent of the crop each year (Anderson 1964). Hypoxylon canker infections seem to be established in a "wave year" pattern (Schmiege and Anderson 1960), although climatic variation is not known to be responsible.

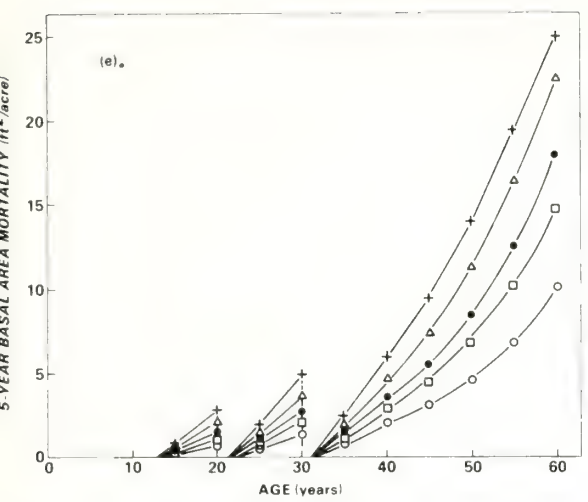
Although the general relations between tree growth and growing season climate have been recognized, I know of no published studies that have included climatic variation in stand growth equations. Climatic data need not come from on-site weather stations because standard climatic records up to 20 miles distant are usable (Fritts


(a)
STAND BASAL AREA (ft²/acre)
AGE (years)
Trees per acre at age
10 20 30
2000 1000 500
1500 750 375
1000 500 250
750 375 188
500 250 125
4600 1990 1000 (Unthinned)


(b)
MEAN STAND D B H (inches)
AGE (years)


(c)
STAND VOLUME >6 d i b (cunits/acre)
AGE (years)


(d)
STAND VOLUME >8 d i b (cunits/acre)
AGE (years)



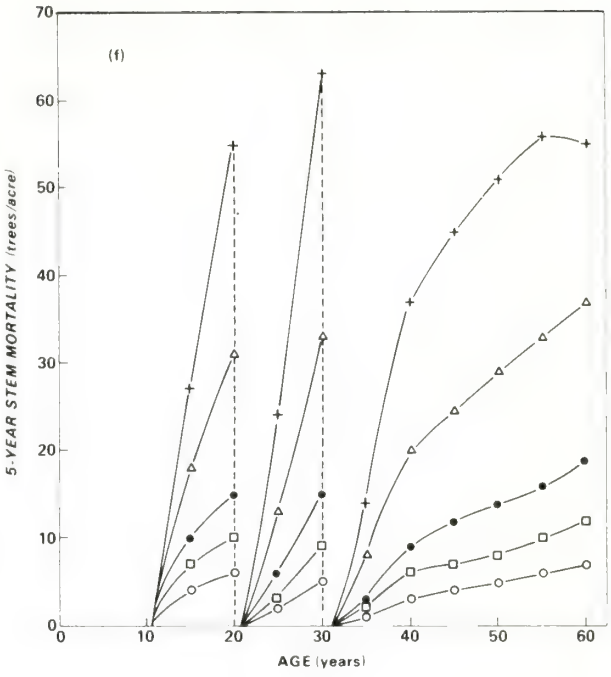


Figure 1.—*The effect of thinning to various stem densities at ages 10, 20, and 30 on (a) stand live basal area, (b) mean stand diameter, (c) volume to a 6-inch top, (d) volume to an 8-inch top, (e) 5-year basal area mortality, and (f) 5-year stem mortality.*

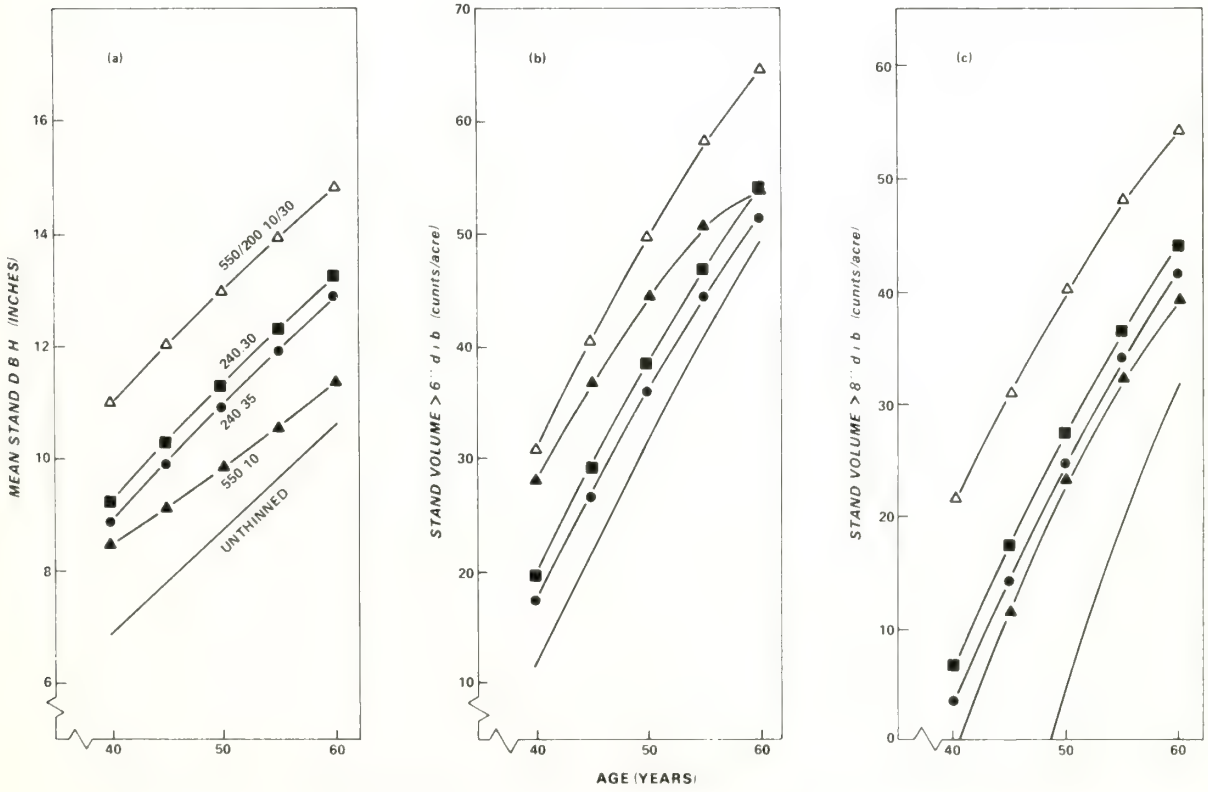


Figure 2.—*The effect of various thinning timings and frequencies on (a) mean stand diameter, (b) volume to a 6-inch top, and (c) volume to an 8-inch top.*

1976). Soil moisture under forest cover can be accurately estimated from Thornthwaite and Mather's (1955) computations if surface infiltration and internal drainage are good (Zahner 1967).

Three assumptions made in this study could lead to errors in computation of soil moisture and its availability to tree growth. First, the assumption that soil moisture is at field capacity by May 1 is not always valid. During a recent record drought, soil moisture under aspen at the Marcell Experimental Forest (20 miles north of Grand Rapids, Minnesota) was only 12 inches in May 1976 and only 8 inches in May 1977, compared with field capacity of 14 inches.[3] In our study, the climatological data (U.S. Department of Commerce 1926-1975) indicated that precipitation over the recharge period was sufficient to bring soil moisture to field capacity for 43 of the 50 years. Complete year soil moisture calculations for the other 7 years revealed that incomplete recharge led to these soil moisture overestimates:

Year:	1928	1931	1932	1934	1935	1956	1961
Overestimate (inches),							
June:	1.26	4.18	1.63	3.00	1.61	0.37	0.56
July:	1.13	3.69	1.45	2.31	1.58	0.33	.48

Because these errors are diluted in 5-year averages, the errors in the computed climate variables are small (0.5 to 5.2 percent overestimates) and do not detract seriously from this analysis. However, the assumption of full soil moisture recharge should not always be accepted outright.

The second assumption, that the rooting zone for aspen remained constant at 6.7 feet during the entire study, could be questioned. Practically nothing is known about changes in aspen rooting with age, but some inferences can be drawn from hydrologic observations. The increased water yield after clearcutting aspen steadily diminishes until stabilizing at about age 8 to mature forest levels.[3] This indicates full occupation of the rooting zone by the sucker stand, and little change would be expected thereafter. Thus, the second assumption appears to be valid.

The third assumption is that the rooting profile of aspen is indeed 6.7 feet. This depth is taken directly from Thornthwaite and Mather (1955) for closed mature forest. Verry[3] has observed soil moisture depletion as deep as 7.5 feet under mature aspen, indicating rooting occurs at that depth. The 6.7-foot assumption is not as important for this study as it would be for a larger study that included sites with different soil textures and moisture capacities. Such a study would need to determine absolute amounts of water available for tree growth on each site.

It should not be inferred that growing season soil moisture and air temperature are the only climatic variables affecting aspen growth. The total effect of climate on aspen growth is underestimated by this model because the growth analysis is restricted to the current season and records of solar radiation, wind, and other climatic variables are not available.

In this study, neither gross basal area growth (ΔBg) nor mortality basal area (Bm) reacted to soil moisture independently from temperature; both responded best to June and July monthly interactions of soil moisture and temperature.

For ΔBg (equation 1, table 3), the combined climatic variable, $M(/nF)$, suggests that aspen growth increases more as a result of increased soil moisture than as a result of increased air temperature. An inspection of the magnitude of the coefficients in equation (1) shows that July is 70 percent more important than June as a growing month (table 4). The same combined climatic variable for August had no additional effect on ΔBg. This agrees with the observations of Fraser (1962), who found that the bulk of radial growth of aspen in Ontario occurs in July and is nearly complete by August.

The best combined climatic variable for Bm (equation 2, table 3) was $(/nM)/F$, again for June and July only, but for 5-year means 3 and 9 years earlier, respectively. (See table 2 for computation.) The coefficient for June was positive and the coefficient for July was negative (table 4), meaning that mortality increased with a cool, wet June 3 years previous and a hot, dry July 9 years previous. This interpretation has some biological support: the 3-year lag (four growing seasons including current year) response to June climate falls nicely in the range of 3 to 7 years needed by hypoxylon to kill pole-sized trees (Schipper and Anderson 1976). This may be a clue to understanding the infection mode of hypoxylon. The hot, dry summers that favor *Armillaria mellea* root rot may not injure

[3]*Personal communication with E. S. Verry, Forest Hydrologist, North Central Forest Experiment Station, Grand Rapids, Minnesota, March 2, 1978.*

spen as seriously, and trees may take longer to ie—thus the 9-year lag response to July climate.

Most of the variation in height growth (ΔH, equation 4) was accounted for by increase in mean tand d.b.h., which is dependent on net changes in asal area (from equations 1 and 2) and numbers of rees (from equations 2 and 3). Because both ΔBg nd Bm responded to combined climatic variables, H has already responded to climate.

Figure 3 shows the upper and lower bounds and xamples of stand basal area net growth and 5-ear mortality basal area calculated from equations (1), (2), (3), and (6) using the climate "loop" escribed in "Methods". Note that the bounds do ot represent any single run but rather define the mplitude that can be expected at each 5-years' rowth with successive runs having different tarting points on the climate "loop". The surprising result is that stand conditions are similar after 0 years of growth regardless of when favorable or unfavorable climatic conditions were introduced. This is not as apparent in figure 3 for mortality, which was plotted as 5-year values for clarity, but when plotted as accumulated values, the pattern is similar to basal area growth.

Basal area growth, 5-year mortality, and mean stand diameter are shown in figure 4 for a stand grown with constant "best", "average", or "worst" climate based on the extremes and mean 5-year soil moisture and air temperature interaction terms calculated from this study. The growth response to the worst climate was not nearly as dramatic as to the best climate. Aspen grown during the worst climate had 19 percent less basal area, 8 percent smaller stand d.b.h., and 26 percent less volume in 8-inch bolts (not shown in figure 4) at age 50 than aspen grown with average climate. Aspen grown during the best climate averaged 4 inches larger in d.b.h. and had nearly twice as much basal area and volume in 8-inch bolts as

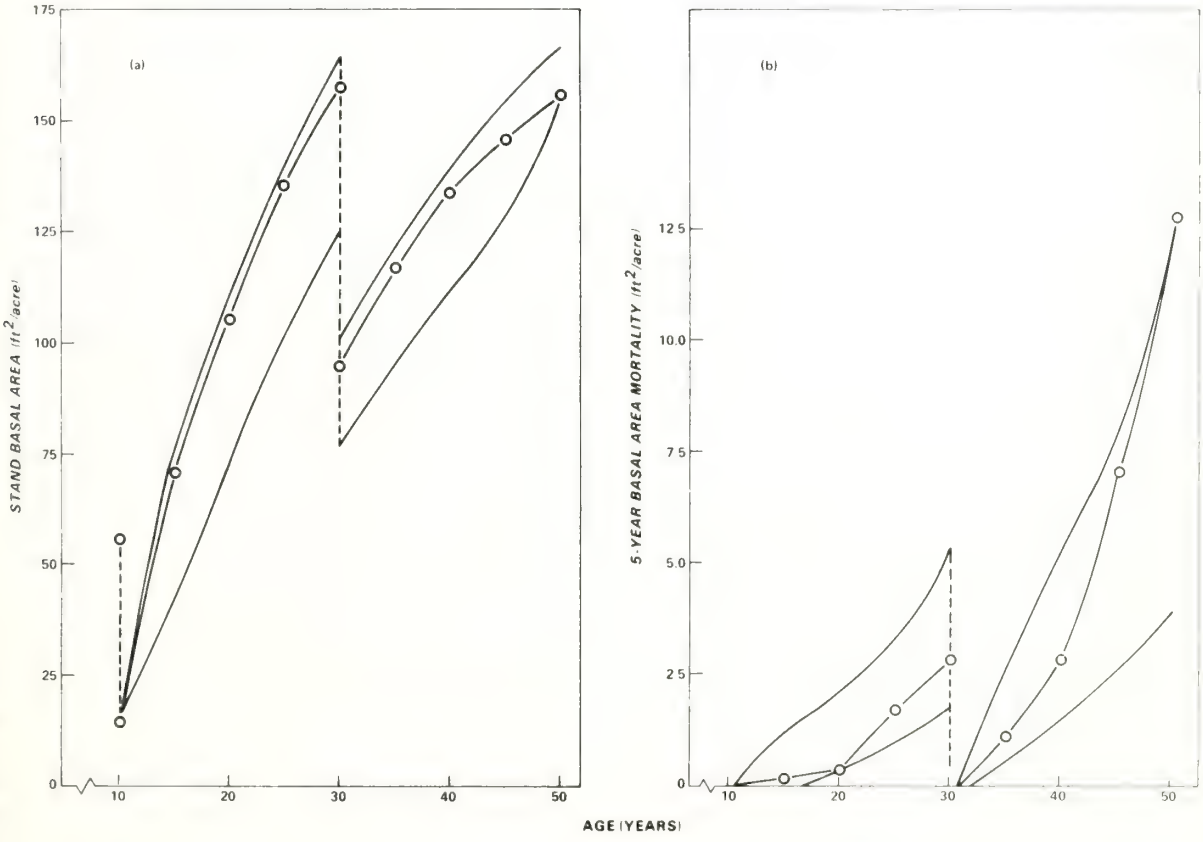
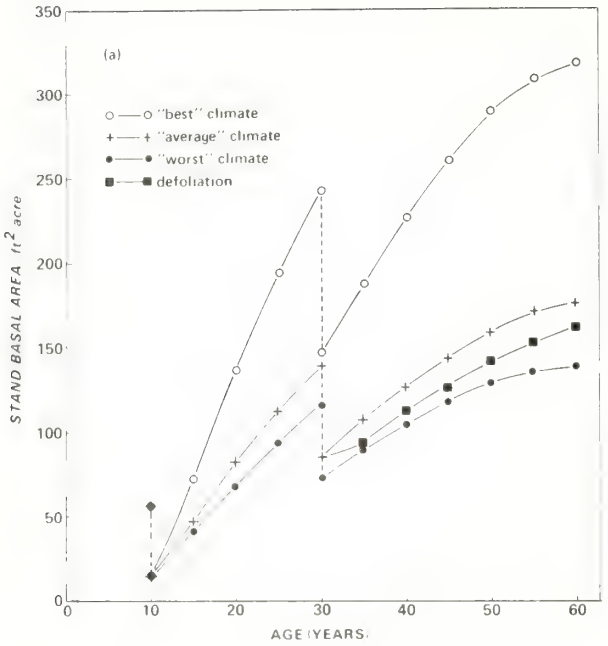
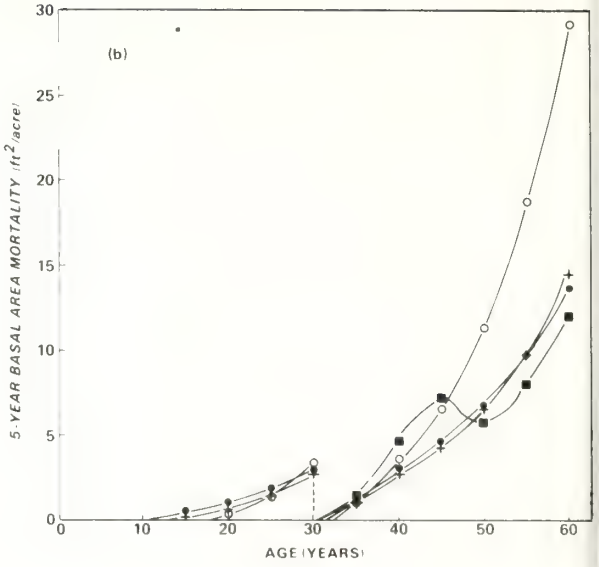
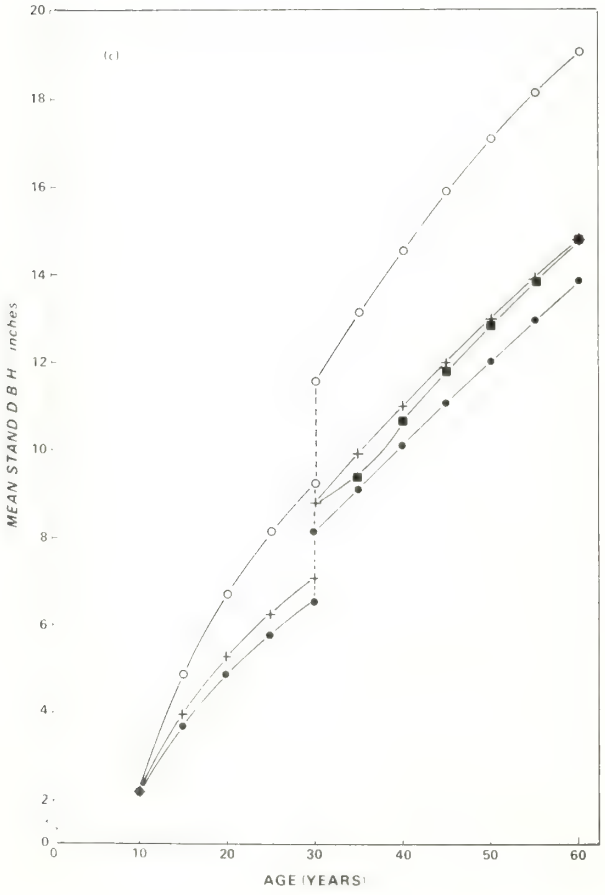


Figure 3.—*The effect of varying 5-year growing season climate on (a) live basal area, and (b) 5-year basal area mortality after thinning to 550 and 200 stems per acre at ages 10 and 30, respectively. See text for details.*







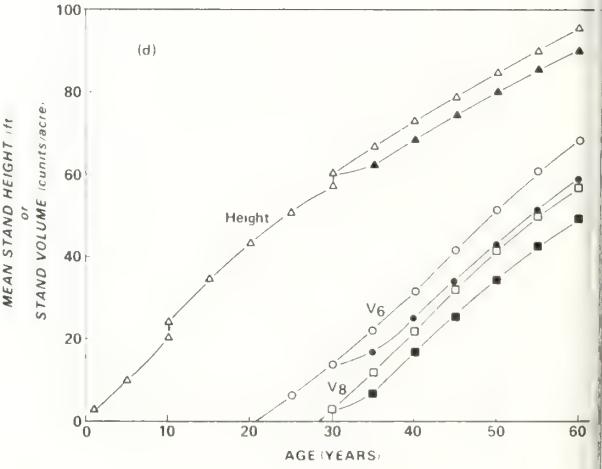


Figure 4.—*The effect of constant "best", "average" and "worst" climate on (a) live basal area, (b) 5-year basal area mortality, and (c) mean stand diameter. The thinning strategy is the same as in figure 3. Also shown is the effect of forest tent caterpillar defoliation (with "average" climate) on these same growth variables. In (d), mean stand height and volumes to 6-inch (V_6) and 8-inch (V_8) tops are shown for "average" climate. Shaded symbols show the effect of defoliation.*

spen grown with average climate at the same ge. Of course, these are extrapolations; continued best" or "worst" climate could induce unforeseen rowth or mortality reactions that would not occur uring varying climate.

The main value of these simulations is they how (1) that aspen growth is little affected by ombinations of favorable and unfavorable grow- ng years that have the same long-term average; 2) that continued adverse climate (at least within he limits of the past 40 years) does not necessarily resent an unacceptably grave risk to aspen man- gement; and (3) that favorable climate could oost aspen growth tremendously. This also sug- ests the magnitude of aspen growth response to rrigation, since soil moisture is the major contrib- tor to the climate response.

Forest Tent Caterpillar Defoliation

Aspen stands commonly suffer temporary incre- ent loss and mortality from periodic outbreaks of efoliating insects such as the forest tent caterpil- ar and the large aspen tortrix (*Choristoneura onflictana* Walker). Forest tent caterpillar popu- ations erupt following an increase of annual cy- lonic passages (Wellington 1952).

Forest tent caterpillar defoliation was an impor- ant variable in all growth equations (equations 1 o 4). Defoliation reduced gross basal area growth ΔBg) and height growth (ΔH), and increased mor- ality basal area (Bm) in smaller trees up to 8 ears later. This seems realistic because small rees that are suppressed and clearly under stress uffer most from defoliation (Kulman 1971, Witter *t al.* 1975). From 8 to 18 years following defolia- ion Bm was still elevated, peaking at 13 years (see igure 4), although size of trees dying was no long- r affected. This 13-year delay in peak mortality lso seems reasonable, because defoliation exerts stress on the tree that is not immediately fatal ut that subtly tips the balance of survival, per- aps much like the stress induced by hot, dry Ju- y's discussed earlier. Barter and Cameron (1955) eported increased mortality the first 3 years after efoliation in 60-year-old aspen, but in general, 3 o 4 years of defoliation causes little mortality Kulman 1971). The increased mortality found in his study was not great and would not have been detected without accounting for the several other variables affecting Bm. In contrast, Witter *et al.* (1975) reported reductions in aspen stem density and basal area of 41 and 27 percent, respectively, after 5 to 7 consecutive years of heavy defoliation.

There is no doubt that defoliation decreases ΔBg (Ghent 1958, Rose 1958), especially after account- ing for variation in summer rainfall (Duncan and Hodson 1958). Batzer (1955) reported crown die- back when aspens were repeatedly defoliated by forest tent caterpillars, which could explain the reduction in ΔH by defoliation (equation 4).

Simulated defoliation effects are shown in fig- ure 4. Note the mortality peak during the third 5- year growth period. The total mortality due to defoliation during the four subsequent growth per- iods was only 30 percent above normal basal area mortality, but 57 percent above normal stem mor- tality. Since this acted as a thinning from below, mean stand d.b.h. was not affected nearly as much at age 50 as were other parameters. The effect on height growth is particularly important because mean stand height was reduced 5 feet at age 50. Since dominant height is proportional to mean stand height, large errors in measured site index are possible, especially in stands suffering more than one defoliation period. Productive potential of such stands could be considerably underesti- mated. In this simulation, sawtimber and veneer volume was reduced 17 percent at age 50 by defoliation.

In addition to the 550/200 thinnning strategy, the effect of the same specified defoliation was simulated using the 1,000/500/250 strategy (table 6, Appendix). Defoliation reduced V_s more than Vbw, and reduced V_s most, at least initially, in the 1,000/500/250 strategy, which has the greater stand density. Even though defoliation volumes slowly gained parity with no defoliation, the growth loss would not be completely made up prior to pathological rotation.

CONCLUSIONS

The primary objective of thinning is to concen- trate growth on crop trees to increase the yield of large-diameter products. Secondary objectives may be to increase the total fiber yield by salvag- ing anticipated mortality, to bring early financial

return from commercial thinnings, to reduce the cost of logging during the regeneration cut, and to improve regeneration conditions for aspen suckers. Another possible objective in aspen is to upgrade the genetic composition of the stand by removing undesirable clones in thinnings.

Even though the model presented here was developed from data from a single site, the proportionate gains (if not absolute gains) in sawtimber and veneer bolts as a result of thinning should be representative for most site index 80 stands. How stands of higher or lower site quality respond to thinning is not known with certainty, although response usually increases with site quality.

Thinnings should be from below except to remove defective and risk trees. The first thinning may deviate from strictly regular spacing in order to keep the best trees. Occasional clumps of close-growing, vigorous trees can be left until a later commercial thinning to provide the widest latitude in crop tree selection. The final thinning, however, should be regularly spaced because of the long wait until the regeneration cut. Great care should be taken during thinning to avoid injury to crop trees. Aspen is extremely sensitive to wounds, which serve as an entry point for defect and decay. The risk of wounding is highest during spring and early summer when the bark slips easily; thus, thinnings should be scheduled during the dormant season. For more thinning information, see Brinkman and Roe (1975) and Perala (1977).

As this analysis has demonstrated, long-term forest growth records and standard local climatological records can be used to partition forest growth response to varying climate and insect defoliation. It must be recognized, however, that the climate response model developed here is limited to stands on very specific soils (see Appendix). Zahner (1967) points out that soils that have considerable storm runoff, receive downslope soil moisture, or have seasonally perched water tables present quite different soil moisture regimes than do soils with good internal drainage and flat topography. Stoeckeler (1960) found that aspen site index varied widely with soil percent silt-plus-clay, depth to water table, internal drainage, slope, and aspect. Moisture availability for tree growth is greatly affected by all these variables and must be accounted for in any modeling attempt involving climatic response.

The stronger response of basal area growth and basal area mortality to the combined climatic variables than to separate soil moisture and air temperature variables implies a synergistic growth response to soil moisture and temperature. A problem with using a combined variable is that much trial and error is needed to find the combination and form of variables that provide the correct response curve, such as M(/nF) and (/nM)/F in this study. Although these interaction terms performed well here, they may be much less adequate for other soils, as suggested in the model tests (see Appendix). Even coding or choosing the units of measure affects the relation with dependent variables when logarithmic and arithmetic units are combined.

It should be possible to develop a map of aspen productivity on well-drained soils throughout its eastern range. A model responding to geographic variation in growing season temperatures, computed soil moisture, and probably latitudinal variation in solar radiation would be needed. This concept has already had some success in Europe (Pardé 1959, Paterson 1959) and the western United States (Jones 1971). Refinements for topographic positions, depth to water table, and other site variables could be added and the confounding factor of aspen clonal variation would need to be resolved (Jones 1971).

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APPENDIX

MODEL RELIABILITY

The equations in the model have high statistical iability (i.e., high R^2 and low sy.x, table 3), rtly because the data are gathered from a single, iform study area. The repeated measurements ve the disadvantage of introducing an unestim-le error, usually small, due to autocorrelation ., the error terms are underestimated). On the ner hand, the study is unique in providing data er an entire 53-year rotation for thinned aspen. oreover, many growth remeasurements are nec-sary to partition the effects of varying climate d defoliation from stand age and density.

Coefficient significances are at least $p<0.05$ in uations (1), (4), (5), and (6), and for all terms in uation (3) except $ln(1+T_d^y)$, which is $p<0.1$ (ta-e 4). Equation (2) contains a number of variables at under usual statistical interpretation (if 0.05) would be deleted. However, one goal in e analysis was to find the combination of varia-es that would eliminate any trend of residuals out time; this required retaining variables that oduce biological responses according to existing owledge or theory even if they had limited sta-tical significance. Considering the highly varia-e nature of mortality and the fact that mortality individual trees is not incrementally measured tree is either dead or alive, which often varies th observer judgment), it was further felt 0.05 was too strict a requirement for this study. e statistical risk of erroneously retaining a ven variable in the mortality equation is high, t the practical risk is low, because mortality in ltiple thinned aspen is a minor component of nd growth.

One way to evaluate the reliability of these uations is by testing them against independ-tly observed values from other studies.

TESTING THE MODEL

The first step was computing, as described in lethods," the combined climate variables based climatological records from the weather station arest each study. Maximum soil moisture reten-n for each stand was assumed identical to this study—i.e., 14 inches. Then growth was predicted based on stand parameters and either including or ignoring climatic variability and defoliation. Deviations of observed values from values predicted when ignoring climatic variability or defoliation were then plotted over the contribution predicted for each. Finally, deviations of observed values from predicted values for study H-70 (others did not have enough observations) were plotted over the equation stand variables to detect bias.

Generally, predicted basal area growth was closest to growth observed in stands thinned at ages 7 to 15 (table 7). Deviations of basal area and height growth from observed values were usually consistently biased within a stand, rather than random, when climate was included. In contrast, when climate was ignored the deviations were random.

Gross basal area growth (ΔBg) comparisons were available from studies H-70, NC-93, DM, and BC (table 7). In H-70, ΔBg was consistently overestimated by 13 to 35 percent (4 to 5 square feet/acre/5 years) with climate included. The check of deviations with climate-ignored over climate-predicted response showed a strong 1:1 positive slope, indicating the same climatic response as in the primary study on the same soil nearby. The site index for H-70 is about 7 feet less than in the primary study, which could account for the consistent overestimate. There was no trend of deviations over observed stand parameters in H-70.

ΔBg for study DM was greatly overestimated for the first growth period after thinning, but was estimated perfectly for the second growth period. A great deal of bark splitting and poplar borer (*Saperda calcarata* Say) injury was noted at the first 5-year remeasurement after thinning, indicating stress in the stand. The equation-predicted climatic effect was more favorable in the first growth period than in the second, so some other unknown factor is probably responsible.

In younger stands, ΔBg was predicted closely in NC-93. In study BC, ΔBg was unexplainably overestimated at age 7 and underestimated at ages 12 and 17. These low estimates are probably due to the higher site index of study BC and, at age 17, an additional error from overestimating growth reduction by forest tent caterpillar defoliation. De-

foliation was nearly 100 percent during one year but no defoliation was observed during the other years. This probably has less effect on radial growth than three successive years of much lighter defoliation, as was experienced on the primary study. Five-year climate during these three growth periods varied little and presumably did not account for any of this variation.

In constrast with ΔBg, predicted basal area mortality (Bm) and stem mortality (Nm) varied widely from observed values (table 7). In general, mortality was greatly overestimated in studies H-70 and M-371, and greatly underestimated in NC-52i, NC-93, and BC. Since most mortality was by hypoxylon canker and resistance to hypoxylon varies widely among clones (Copony and Barnes 1974), it is not surprising to find wide variation in mortality among stands. The model estimates for mortality are biased consistently within stands, except that mortality is greatly underestimated for the first growth period after thinning stands age 20 or older. Pole-sized aspen can suffer sunscald when suddenly released, but sapling stands apparently are not affected. Because the model was developed from aspen thinned initially as saplings, later pole-sized thinnings did not induce abrupt changes that would increase mortality. In fact, equation (2) predicts less mortality during the first growth period following thinning, because poor risk trees are specified in the thinnings. Thus the model erroneously underestimates mortality in the first 5 years after initial thinning in pole-sized stands.

The test of climatic effects on Bm showed that H-70 responded much like the primary study—i.e., Bm increased with increasing computed contributions by climate. Studies DM and BC showed no logical trend over variation in climate, suggesting that mortality is more strongly controlled by site and genotype than by climate.

Where mortality is inaccurately predicted, it follows that net basal area growth (ΔBn = ΔBg− Bm) is predicted less accurately than is ΔBg. ΔBn was predicted closely only in the studies (BC and PN-3, 8; PN-1, 6; PN-2, 7) that were thinned at ages 7 to 15 (table 7). Although such comparisons are limited to only 12 growth periods, it is encouraging to find these close agreements between predicted and observed values of ΔBn, the variable of most practical interest to the land manager.

Predicted mean stand height growth (ΔH) varied widely from observed values but was consistently biased within a stand (table 7). In H-70 and M-371 the model tended to increasingly overestimate ΔH with age, confirming the difference in site index and suggesting that height growth slowed earlier than in the primary study. The only deviations from this trend are during the defoliation years when the model overestimated reductions in height growth. The other studies have too few observations to determine if a consistent bias is present in estimating ΔH.

In summary, the model is highly specific in respect to thinning strategy, site index, degree of defoliation, and soil moisture characteristics. The model works best for (1) site index 80 stands; (2) stands thinned initially at about age 10; (3) Warba or similar soils; and (4) stands lightly to moderately defoliated (if at all) over a 2- to 4-year period.

This is not as restrictive as it at first seems. Future thinning programs will concentrate on the best aspen sites, of which site index 80 is most common. About 120,000 acres of the Chippewa National Forest, for example, have Warba soils most of which support site index 75-80 aspen. Extending the model to other areas and soils would show greatest weaknesses in the climatic terms, and the mortality and height growth equations. However, the model should serve as a guide to thinning response until a more universal model is developed.

[4]*Personal communication with Grant Goltz, Soil Scientist, Chippewa National Forest, March 1978.*

Table 6.—*The effect of defoliation on standing total bolewood (Vbw) and veneer bolt (V_8) volume by thinning strategy*
(In percent of no defoliation)

Stand age	550/200		1000/500/250	
	Vbw	V_8	Vbw	V_8
30	100	100	100	100
35	83	58	84	47
40	83	77	85	71
45	83	80	85	77
50	84	83	87	81
55	85	85	90	84
60	87	87	90	86

Table 7.—*Deviation of model-predicted values minus values observed expressed as a percent o in seven other once-thinned aspen studies (climate and defoliation variables in*

Study	T	P	ΔB_g	ΔBn[1]	Bm	Nm	ΔH	F
				percent of observed				
	30	1	+33	+93	−78	−71	+63	N[2] = 9. S[3]
	42	14	+35	+15	+115	+90	+26	Soil = Warb
H−70	47	1	+13	−24	+144	+104	+94	loam. Locate
	52	1	+25	−98	+124	+55	+97	from primary
	57	1	+22	−58	+108	+60	+294	
	20	1	Na[4]	+5	Na	−42	+2	N = 6. S = 7
	35	1	Na	+30	Na	+57	+63	Warba fine s
M−371	40	15	Na	−1	Na	+279	−2	020°, 4.6 mi
	45	1	Na	+132	Na	−17	+88	study.
	19	1	Na	+106	Na	−76	Na	N = 20. S =
NC−52i	24	1	Na	+17	Na	−78	Na	Soil = Warb
	29	1	Na	+141	Na	−78	Na	loam. Locate
								from primary
NC−93	16	1	+4	+30	−91	−93	−34	N = 4. S =
								Soil = Warb
								loam. Locate
								from primary
DM	37	1	+70	−90	−91	−90	+180	N = 4. S =
	42	1	0	+23	−35	+23	+34	= heavy silt
								47° 50′N, 93
								miles from c
								station at Bi
BC[5]	7	1	+32	+31	+∞[6]	+∞[6]	Na	N = 2. S = 9
	12	1	−9	−6	−86	−90	Na	loamy sand
	17	18	−20	+3	−66	−67	Na	Located 160
								official weat
								MN and 255
								International
PN 4,5[5]	4	1	Na	−78	Na	+50	Na	N = 2. S = 6
PN 3,8	7	1	Na	−3	Na	+125	Na	15. Soil =
PN 1,6	10	1	Na	+4	Na	−32	Na	48° 10′ − 4
PN 2,7	15	1	Na	+11	Na	−32	Na	93° 25′ − 9

[1]ΔBn=Net basal area growth. Except where noted, other symbols follow tables 2 and 3.
[2]N=Number of plots.
[3]S=Site index, feet at age 50.
[4]Na=Not available.
[5]Data supplied by John W. Hubbard, Management and Research Forester (retired), Boise Cascade Corporation.
[6]Mortality was predicted but none was observed, therefore the infinite deviation.

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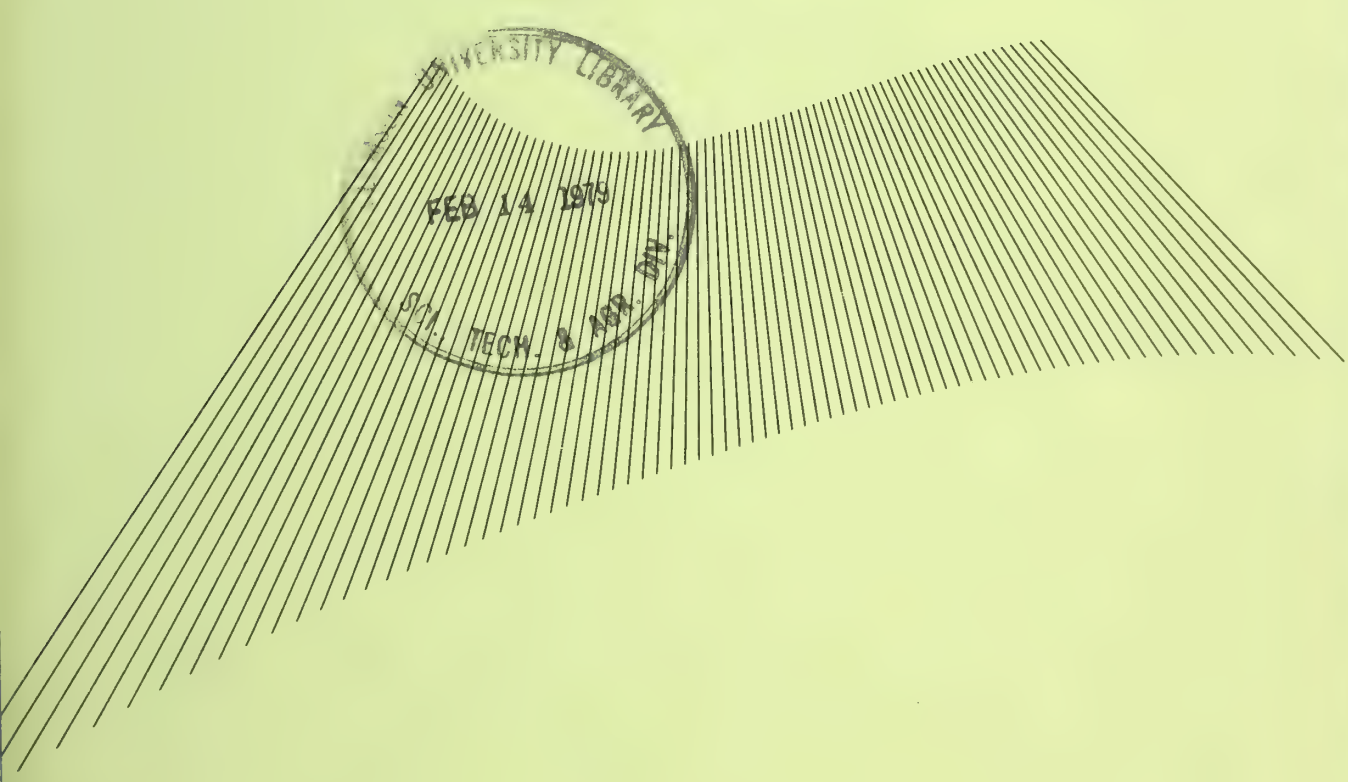
Evaluation of Several Methods of Applying Sewage Effluent to Forested Soils in the Winter



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1992 Folwell Avenue
St. Paul, Minnesota 55108

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1978

EVALUATION OF SEVERAL METHODS OF APPLYING SEWAGE EFFLUENT TO FORESTED SOILS IN THE WINTER

Alfred Ray Harris, *Soil Scientist,*
East Lansing, Michigan

Year-round land application of sewage effluent ay be a necessary alternative for northern comunities where storage facilities are not possible are too costly. Sufficient knowledge and adeuate materials already exist to engineer systems at will supply effluent to the disposal site during orthern winters. Several problems inherent in sposing of effluent on land in northern climates re: (1) limited infiltration of the effluent into the ozen soil, (2) poor distribution of the effluent rough the frozen soil mass, and (3) limited renoative capacity of the plant-soil system because of educed biological activity under low temperature onditions.

Several irrigation systems for effluent applicaon have already been developed for areas with ild winters. Rotating and nonrotating sprinkler stems such as those used by Myers (1966) disibute effluent uniformly, but supercooling from e evaporation of water droplets causes ice to ccumulate and stop sprinkler heads from rotatg. He also found with low pressure systems that e did not form, but effluent distribution was neven.

Effluent has been found to infiltrate frozen forst soils (Nazarov 1969, Sartz 1969, Harris 1972, 976), however, it may be poorly distributed beause of macropore and biopore (openings due to ological activity) channels common to forested ils. These channels conduct and pipe effluent rough the frozen soil (Krumback and White 964, Aubertin 1971, Harris 1972), short circuitg infiltration through the soil mass (Harris 971).

The present report describes a test of five irrigaon systems to: (1) determine their feasibility for se on forest soils during winter, (2) to compare eir installation costs; and (3) to determine frost depth, ice accumulation, and effluent distribution patterns in the frozen soil.

Two subsurface systems and three surface systems were studied. The subsurface systems were: (1) subterranean irrigation in which effluent was flooded through underground perforated tile lines, and (2) hole irrigation in which effluent was injected into evenly spaced vertical holes lined with perforated tile. The surface systems were: (1) furrow irrigation in which effluent was channeled through narrow ditches, (2) flood irrigation in which effluent was flooded between levees, and (3) sprinkler irrigation using rotating sprinkler heads (fig. 1). Water quality was monitored under the furrow irrigation plot.

MATERIALS AND METHODS

The study site is located at Fort McCoy, Wisconsin, near the sewage treatment plant. The soil is a Sparta sand (*Entic hapludoll*) which is well-drained and low in available water capacity, natural fertility, and organic matter content. Vegetation is 40-year-old jack pine (*Pinus banksiana*) intermixed with scrub oak.

Chlorinated secondary effluent was pumped to the site by two 7½ horsepower centrifugal pumps through a 6-inch supply main. The main supply line split into 3-inch mains which supplied effluent to individual plots. During winter, the effluent temperature was approximately 2C at the point of discharge to the plots.

The plots were 0.18 ha (0.44 acre) in area. Each plot was irrigated during the frost-free seasons. With the onset of soil freezing, irrigation was stopped on half of each plot so that the effect of antecedent water content on soil freezing could be

measured and compared with water content in the winter-irrigated soils. Irrigation started in October of 1973 and continued for 2 years. The hole and sprinkler irrigation systems were dropped after the first year and the flooding system was started in the second year (fig. 1). Effluent was applied at the rate of 10 cm/week once a week on a plot area basis in all systems tested. Half of each plot was irrigated year-round and the other half during the growing season only.

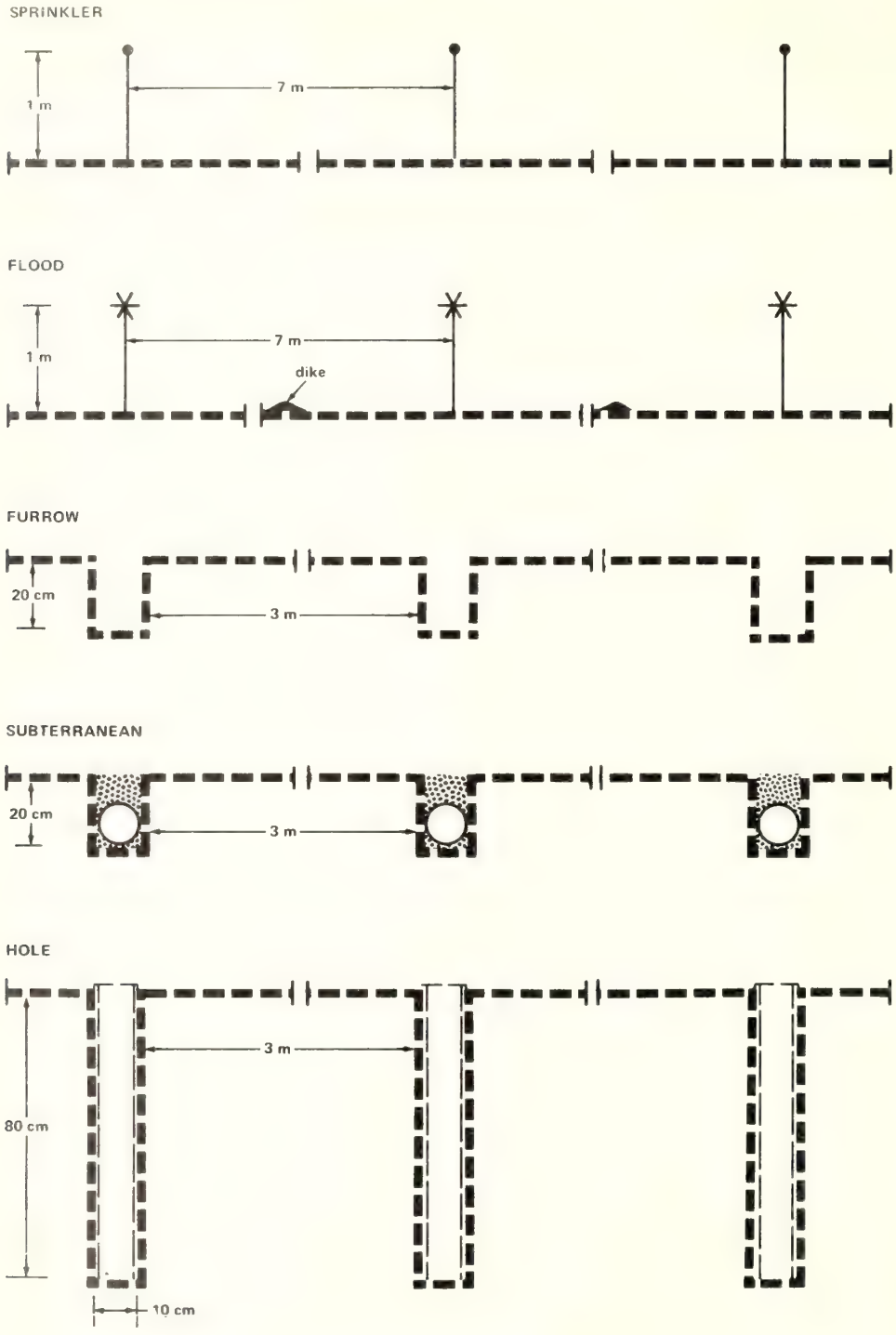

Figure 1.— *Schematic of the five irrigation methods used for winter effluent irrigation.*

Description and Layout of Irrigation Systems

All irrigation system layouts were made as simiar as possible to simplify construction and inimize costs. Laterals were equipped with comercial flow control valves at the point of applicaon. Flow control valves deliver the same rate of ow over a pressure range of 4.2 to 8.4 kg/cm² (60 120 lbs/in²). This made it possible to apply the ffluent uniformly over the plot without the timeonsuming balancing of pressure. The sprinkler ystem was not regulated by flow control valves nd was dependent upon system pressure for deliv-y rate. The flow control valves and sprinklers ere spaced so as to deliver 17 mm (0.67 in) of ffluent per hour. The description of each irrigaon system is as follows:

Sprinkler.— This system was designed for oove-freezing conditions. However, it was operted over the winter 1973-1974 to investigate diffiulties encountered with sprinkler systems under eezing conditions. Sprinklers were spaced 7 m part in a square pattern. The sprinklers delivered 7 mm (0.67 in) per hour of effluent at 2.5 kg/cm² 5 psi) at the sprinkler nozzle. Materials cost 400/plot or $2200/ha.

Furrow.— A trencher was used to make a furw 13 cm wide and 20 cm deep. Trees and tree ots made it difficult to slope the furrow edges. he flow rate was controlled at 19 l/min (5 gpm) by e flow control valves. The stream was split at the nter of each quarter plot and sent in opposite rections toward each end of the furrow. Furrows ere spaced 2 m apart. Materials cost $275/plot or 1530/ha.

Subterranean.— Furrows were dug the same as the furrow plot, then 10 cm (4-in) perforated astic pipe was laid in each furrow and covered ith soil to the level of the original surface. The p of the tile was 10 cm below the soil surface. ffluent was distributed in the same manner as ith the furrow plot. Materials cost $575/plot or 3200/ha.

Hole.— Holes were drilled 0.75 m (2½ ft) deep nd 3 m (10 ft) apart in a square pattern. Ten cm -in) perforated pipe was then capped and 2.8 min (¾ gpm) flow control valves were inserted rough the cap. Materials cost $800/plot or 4500/ha.

Flood.— An area 7 m² diked with soil borders was flooded from the center. This system was operated the second winter by removing the sprinklers and risers and inserting flow control valves. The flooding test was initiated to develop a two-tier irrigation system using sprinklers during the frost-free season and flooding during the frost season.

Labor is not included in the above costs. Because of tile placement the hole and subterranean systems were slightly more labor intensive than the other systems.

Gandahl type frost tubes (Harris 1970) were installed on a diagonal across each plot to measure any gradients in frost depth that might be due to uneven effluent distribution. Frost tubes were placed alternately adjacent to, and midway between, irrigation laterals to measure the frost gradient between laterals. Frozen soil core samples were obtained down to the frost line with an ice corer (Harris 1972). The core was then sectioned and analyzed for bulk density and water content.

A well for measuring water quality was established in the center of the furrow plot and a control well was established outside the plots. Samples were collected periodically from the wells and the chlorinated effluent holding tank during the winter of 1973-1974. Samples were analyzed for nitrate, total nitrogen, total phosphorous, and chloride. Ground water variation with respect to irrigation was also measured.

RESULTS AND DISCUSSION

Three of the five irrigation systems tested operate satisfactorily during winter. No difficult maintenance problems were encountered with the furrow, the subterranean, or the flood irrigation systems. Distribution of effluent under the sprinkler system became uneven early in the winter as nozzles began to ice and sprinkler heads ceased to rotate. In spite of the icing problem a few sprinklers operated satisfactorily throughout the first winter. An ice layer more than 40 cm deep formed under the operating sprinklers. Icing was also a problem in the small flow control valves on the hole irrigation plot. Water droplets would freeze in some of the small valve openings after each irrigation. For these reasons, the sprinkler and hole

irrigation systems were not run the second winter. Some ice did form on the surface of the flood irrigation plot but the ice did not exceed 5-cm thickness.

Average minimum temperatures for the irrigation periods December 1973 through March 1974 was −11C; and for December 1974 through March 1975−14C. However, temperatures as low as −38C were recorded. Snowfall was below normal for the first winter but above normal for the second winter.

Frost Depth

Soil frost depth was dependent on whether the effluent was applied on the surface or subsurface. Frost was deeper in the sprinkler plot than under other systems but because so few sprinklers operated throughout the winter, frost measurements for comparison with other plots could not be obtained. Frost measurements made on core samples removed from the sprinkler plots showed frost depths greater than those in the furrow plot.

The contribution of heat to the soil system by the effluent can be greatly reduced by exposing the effluent to the air when the effluent is applied on the surface. Frost depth was greater under the surface application systems for both winters (fig. 2). Subsurface application systems resulted in frost depths that were less than in surface irrigated plots. To accomplish this the effluent mus be injected several centimeters below the soil su face, which by-passes the soil layers that are mos important in renovating effluent.

Effluent placement affected frost depth. Fros depth was usually greatest near a furrow, subte ranean tile, or hole and decreased as distance fro them increased. Frost depth was partially relate to water content and was usually higher near furrow, tile, or hole.

The effect of antecedent water content on fro depth was measured by comparing nonirrigate controls with the plots irrigated in the growir season and year-round on the furrow and subterr nean systems (fig. 3). Both irrigation schedul resulted in deeper frost than the control, presum ably due to an increase in heat conductivity of th wetter soils. By midwinter, the frost was deep under winter irrigation in the furrow treatmen Soil moisture contents were evidently hig enough in early winter to maximize heat transf in both irrigated plots. Frost depth during the la er part of the winter was significantly less wit year-round subterranean irrigation than wit growing season subterranean irrigation. In th subterranean plot the drier soil layer at the su face probably insulated against heat loss. Subsu face irrigation also introduced more heat into th system because the effluent was not exposed to th surface upon application as in the furrow syste

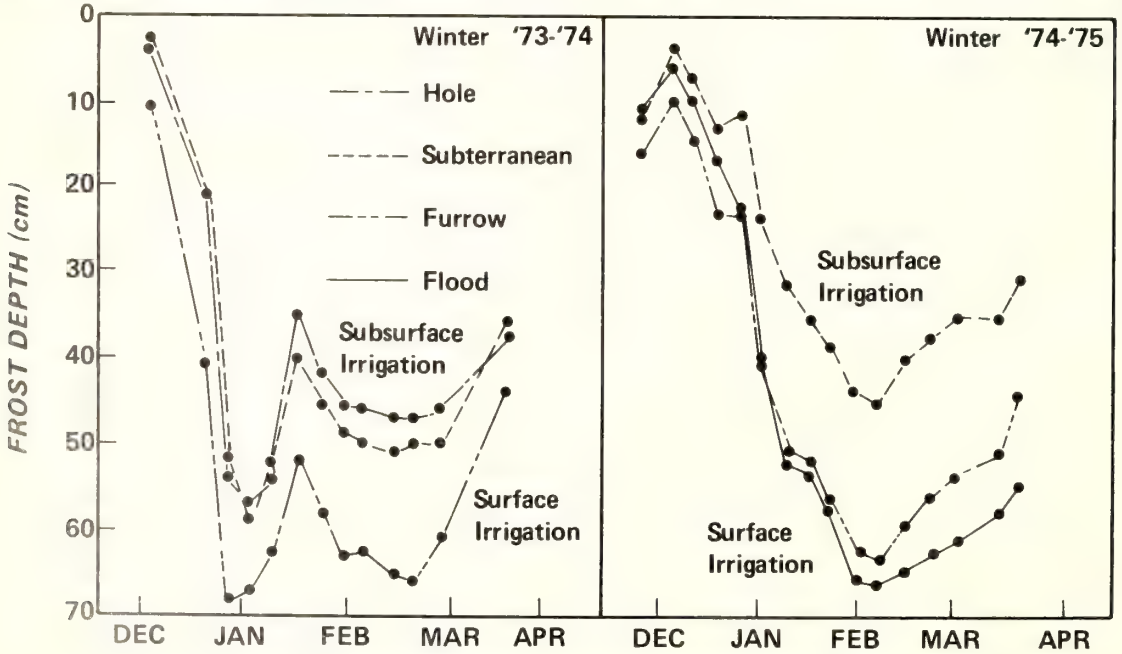

Figure 2.— *Average frost depth with surface and subsurface irrigation.*

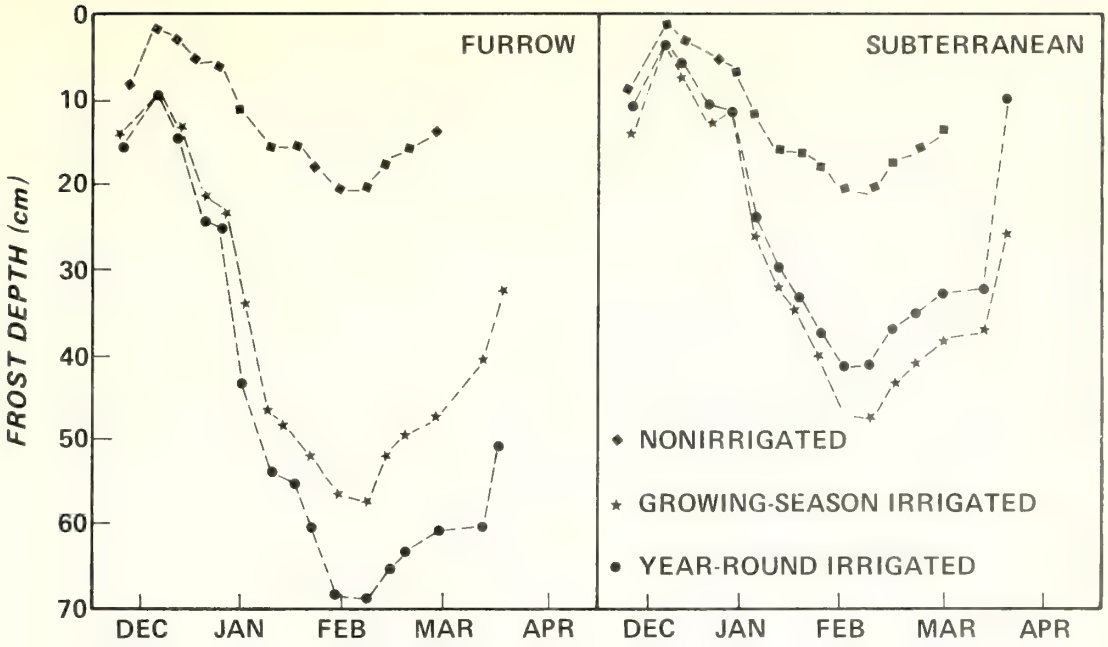

Figure 3.— *Average frost depth among nonirrigated, growing-season irrigated, and year-round irrigated plots for winter of 1974 to 1975.*

is additional heat kept the soil frost from pene-ating as deeply as under plots irrigated during e growing season.

Frost Accumulation

Effluent that accumulated as ice is not directly lated to frost depth. Although the subterranean d hole plots had essentially the same frost pth, the hole plot had water volume percentages mparable to the sprinkler and furrow plots. This as due to the application method. With the fur-w and sprinkler plots, large surface and subsur-ce accumulations of ice were due to exposure to w temperatures; in the hole plot, ice masses ac-mulated around the hole.

Accretion of water in the soil mass by freezing is orm of water storage. In this soil, average field pacities varied from 15 percent at the surface to ercent in the subsoil. Soil ice buildup continues roughout the winter with irrigation (fig. 4). ater content increased in both the furrow and od plots at all depths that were frozen. Effluent red in this way should receive more renovation an effluent leached or piped directly to lower soil pths. However, the overall storage factor is all when compared to the total effluent added. erage stored water above field capacity was 4 to

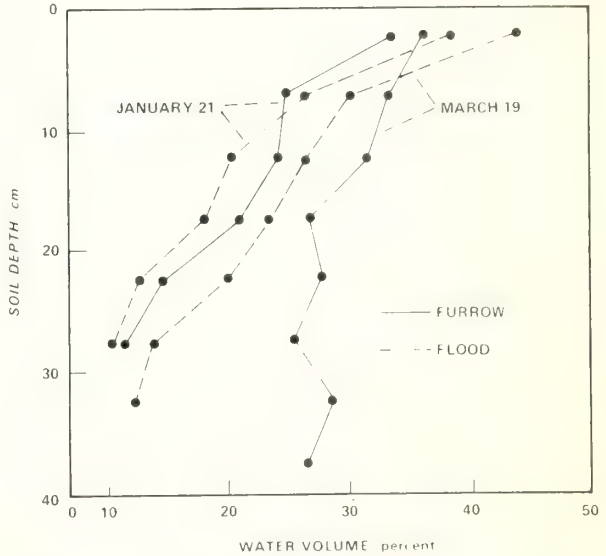

Figure 4.— *Average soil water content for two sampling periods in the furrow and flood plots. Frost depth was 27 and 28 cm for January 21 and 33 and 38 cm for March 19, respectively, for flood and furrow plots, winter of 1974 to 1975.*

8 cm for 1974. This is less than one week's irrigation of 10 cm, accounting for less than 5 percent of the total effluent applied during either winter.

In the winter of 1973-1974, water contents of 33, 42, 44, and 48 percent were found in the surface soil layer of the subterranean, hole, furrow, and sprinkler plots, respectively. Water content decreased with depth until percentages at the maximum frost depth were just higher than unfrozen field capacity values of about 12 to 18 percent. In the winter of 1974-1975, the frost was not as deep or water content as high in the surface soil layer as in the previous year because of the insulating effect of more snow. Water contents of 30, 36, and 43 percent were measured in the surface soil layer on the subterranean, furrow, and flood plots, respectively, in the second winter. Again, water content decreased with depth as in the previous winter.

Effluent Distribution

The distribution of effluent on the soil surface was mainly a characteristic of the application system, however, this relation tends to disappear with depth. The distribution of water in the frozen soil layers at the time of maximum frost depth during the first winter is shown in figure 5.

Injection of effluent in a furrow would be expected to increase the water content more directly beneath that furrow than midway between two furrows. Because of ice buildup and subsequent

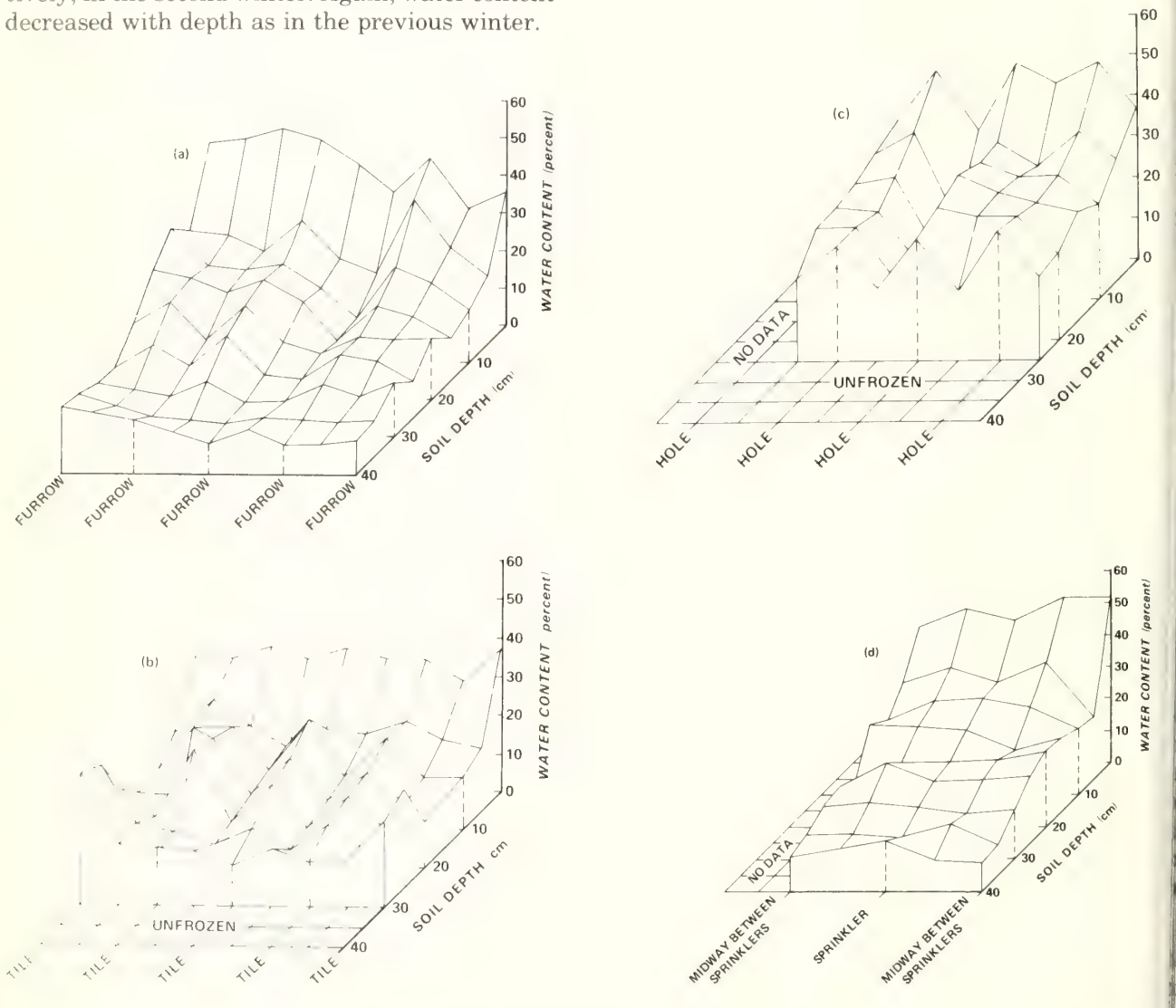

Figure 5.— *Spatial variation of water content with depth in irrigated plots with respect to (a) furrow spacing, (b) subterranean tile spacing, (c) hole spacing, and (d) sprinkler spacing, February 26, 1974.*

ooding between furrows, however, the distribu-
on of water varied greatly (fig. 5a, March 1974).
the flooded areas between furrows the water
ntent (as ice) was higher. The water content did
t always decrease with depth. Localized zones of
gh water content, which had no apparent rela-
on to the way the effluent was applied, were
easured at lower levels. In the second winter soil
ost was less deep and water content was more
iform with depth.

Many of the frozen soil cores showed ice-en-
ched areas around large macropores and bio-
res, indicating that as effluent was being piped
rough large pores some of it moved by capillary
w into the soil mass. These seemingly isolated
eas of high water content do not appear to be
sociated with movement of effluent to a freezing
nt.

The distribution of effluent under the tile sys-
m reflected the position of the tile (fig. 5b). This
fect is more pronounced at the 10-cm depth and
wer than at the surface. Surface enrichment
ust have come mostly from water contributions
snow or rain or capillary movement of effluent
ward the freezing front at the surface. Some iso-
ted ice-enriched areas are also evident under
is plot, indicating that piping is a universal phe-
menon in these soils.

The hole-plot showed much the same pattern as
e subterranean-plot except that distribution dif-
rences were much more pronounced at the
rface (fig. 5c). Distribution of effluent was very
even in this system due to the horizontal dis-
nce the water had to spread through the soil
tween each hole.

The soil moisture pattern at the surface reflects
e distribution around each sprinkler head (fig.
). Winter effluent distribution within the soil
ass was not much better than in the other sys-
ms. However, once a thick surface ice layer is
rmed under the sprinkler, the distribution of any
frozen effluent under the ice layer may be quite
dependent of the sprinkler pattern.

The 1974 to 1975 distribution patterns, because
shallower frost, were not as descriptive as the
evious year. However, frost depths were still
even indicating that piping is a major source of
luent infiltration. The flood plot showed some of
e same distribution patterns as the sprinkler
t.

The ultimate distribution of effluent depends largely on a combination of initial distribution pattern and a secondary pattern due to effluent being piped through the soil by large macropores and biopores. However, movement to a freezing front under temperature gradients also has an effect on distribution with depth (fig. 4).

Effluent distribution will change from winter to winter as the plot undergoes natural modification under the imposed ecosystem. This was well demonstrated in the furrow plot which had a pattern more similar to the subterranean plot in the second winter. There was no vegetation or leaves in the furrows the first winter and the channels quickly froze decreasing permeability to the point where effluent overflowed and flooded between the furrows. Grass and dead leaves accumulated in the furrows over the second year of irrigation. This accumulation combined with a deeper snow cover, kept the furrows partially unfrozen during the winter, resulting in very little overflow between furrows, and more vertical infiltration.

Water Quality

Although an in-depth water quality study was not carried out in this study, the monitoring well in the furrow plot indicates that mobile ions such as nitrate and chloride will move readily through the soil (table 1). With the low soil temperature and no vegetative uptake, renovation of the nitrogen in the effluent is not expected, and in fact did not occur. Since the storage of nitrogen, particularly nitrate, in the soil is so small, effluents must contain small amounts of nitrogen to prevent contamination of ground water. Phosphorous was readily absorbed by the soil, so it should not be a problem with winter irrigation.

Table 1.— *Average nutrient values for effluent and wells at Fort McCoy, Wisconsin, winter of 1973 to 1974*

Item	Nutrient values			
	NO_3-N	Total N	Total P	Cl
	ppm			
Effluent	3.00	4.26	1.47	6.4
Control Plot Well	0.44	0.82	0.29	3.2
Furrow Plot Well	3.60	4.65	0.20	6.1

RECOMMENDATION BASED ON INSTALLATION COST

Because material costs have changed so rapidly, only relative costs are meaningful for each system. The furrow and flood method would be most economical to use. However, if the flood system were combined with the sprinkler system the cost would be only slightly more than the sprinkler system since almost the same hardware could be used for both. This combination would be good for distributing effluent year around. Besides diking between sprinklers some additional hardware would need to be added to the sprinkler uprights for easy conversion. Labor and operational costs were not measured or evaluated.

SUMMARY AND CONCLUSIONS

Sprinkler, furrow, and flood irrigation systems expose the effluent to the prevailing weather resulting in heat loss, deeper soil frost, and surface ice accumulation. The subterranean and hole irrigation systems inject the effluent below the soil surface decreasing heat loss from the effluent which results in shallower frost penetration.

Distribution of effluent in the frozen soil mass was uneven for all the irrigation systems. Closer spacing between irrigation laterals should improve effluent distribution for the furrow and subterranean systems but may not be cost effective. Distribution was a function of the surface wetting pattern, piping due to macropores and biopores, and movement due to temperature gradients. Large macropores and biopores transport water into the subsoil by-passing surface horizons. This one phenomenon may account for the large volume of effluent percolated through a frozen forested soil during winter irrigation.

Nitrate which moves readily through the soil appears to be the limiting factor in winter irrigation. Only effluent with low nitrate concentrations should be used for winter irrigation. Phosphorous renovation seems to be adequate. This is probably true for most of the readily adsorbed chemicals and filterable solids in the effluent. Research on survival of pathogens in the winter will need to be studied. Where TSS, BOD, and phosphorous removal is fairly restrictive for stream discharge, winter application to forested soils may be a better solution.

A flood or furrow system would be the most economical to install. The best year-round effluent distribution is a two-tier system using sprinklers for the growing season and flooding for winter irrigation. Where icing and frost penetration is critical, subterranean irrigation should be considered. Whichever system is used will depend somewhat on the site management requirements.

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OXFORD: 114.12:U628.36. KEY WORDS: Soil water renovation, infiltrations, soil heat loss, soil water movement, effluent distribution.

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EQUATIONS

for estimating stand establishment, release, and thinning costs in the Lake States.

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Forest Service, U.S. Department of Agriculture

This paper is a contribution from the Aspen-Birch-Conifer Program. The Aspen-Birch-Conifer Program is a coordinated, multi-disciplinary research effort. Its mission is to increase and integrate knowledge of the aspen-birch-conifer forests of the northern Great Lakes Region in order to better identify and evaluate resource management alternatives.

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EQUATIONS FOR ESTIMATING STAND ESTABLISHMENT, RELEASE, AND THINNING COSTS IN THE LAKE STATES

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and **Dietmar Rose,** *Associate Professor,*
University of Minnesota, St. Paul, Minnesota

Cost estimates are required as basic inputs hen evaluating forest management projects, al-cating funds, and planning programs. Forest anagers often do not have the data necessary to elate project cost to resource and job factors. Cost stimates, applicable over a wide geographic area nd a variety of forest conditions, would be useful reviewing the potential benefit of forest treat-ents and in better understanding the costs of rest management.

The Lake States of Minnesota, Michigan, and Visconsin have a wide diversity of forest condi-ons. Within this region, certain common treat-ents, such as site preparation and planting make p a significant share of the cost of forest manage-ent. Treatment costs vary widely from project to roject, and much of the variation can be attrib-ted to either resource or job conditions.

Wickstrom and Alley (1967) point out that due the lack of uniformity from one job to the next, eatment costs must be modified by the effect of rtain other factors such as: (1) size of area eated; (2) accessibility; (3) work done such as mber of trees planted, size and number of trees lled, etc.; (4) work conditions such as brush cov-, down material, slope, and soil type.

Yoho, Dutrow, and Moak (1969) presented aver-e costs of treatments commonly carried out in e Southeast. Cost estimates were based on re-onse of forest landowners to a questionnaire. Because such cost averages cannot account for a variety of forest or job conditions, they are limited in application.

Hillicker, Webster, and Tritch (1969) studied the cost of forest treatments in Wisconsin and found that certain factors could be used as primary cost determinants. Project costs were estimated in terms of hours rather than in their dollar equivalents; thus, the cost estimators were likely to be applicable to more cases and for a longer time since the cost was not affected by variations in wage rates, cost of materials, and inflation. The equations they developed are limited, however, by the small sample size and the time that has passed since their results were reported. As a result, new cost estimates are needed for the Lake States.

Conkin (1971) identified several factors that were expected to influence input times for forest treatments. However, because so few observations of costs were available, Conkin was able to develop only a few relations, and for some treatments could only report an average cost.

Although these studies provide suggestions as to factors affecting costs, the results reported are either too limited in scope or too outdated to be used directly in estimating current costs for forest treatments in the Lake States.

This paper presents the results of a study to develop more current estimates of the costs of silvicultural treatments in the Lake States.

PROCEDURES

Public and private forest landowners in the Lake States were contacted to obtain data for the study. One of the authors visited each landowner (either a public land management agency or a corporation) that indicated willingness to participate. After we reviewed their records we eliminated all but two of them. The two chosen, both public land managment agencies in Minnesota and Michigan, kept detailed records of each project undertaken, including:

(1) location and type of treatment project
(2) system used in carrying out the project
(3) size of the area treated
(4) factors that measure the amount of work done
(5) other factors that influence cost
(6) labor cost
(7) supervisory cost
(8) equipment cost
(9) cost of materials used
(10) total project cost in dollars.

The first five data categories in the list above were used as independent variables. Data were available to develop cost equations for six treatments: hand plant, machine site-preparation, aerial spray, prescribe burn, manual release, and thin.

Regressions were run of total project cost against the independent variables listed for each forest treatment. Variables to be included in each treatment equation were selected using Mallows' C_p statistic[1] as computed by an interactive computer program.[2] The program allows the user to select the best fitting model from the set of possible regressions. This is done through inspection of residuals and the behavior of the model over the range of the data. Only direct project costs were included wherever possible, although overhead costs may have been included as a part of the project cost when reports were prepared. No control over how the data was reported was possible. Data was taken for projects completed during January 1 to December 31, 1976.

It was theorized that the total cost of a treatment project could be expressed as an equation of the following form:

$$TPC = FC + VC$$

where:

TPC = total project cost
FC = fixed project costs
VC = variable project costs expressed as some function of independent variables

Regression analysis was used to fit an equation of the general form shown above to the samples for each specific treatment system and method. Functions to estimate the cost per acre of treatment projects were not developed directly since the variance in cost is greater for smaller projects than for larger projects, making it necessary to weight the samples by project size (Wickstrom and Alley 1967). Estimated cost per acre may be found by dividing the estimated cost of the total project by project acreage.

Total project acreage (AC) was expected to be important in all six treatment cost functions. In addition, trees planted per acre (TPA) was expected to be a consideration in planting, basal area removed (BAR) in thinning and manual release. Dummy values were assigned in estimating machine site preparation projects, separating type of operation (OP) into pulling (−1) and pushing (+1). Important independent variables, and their minimum, maximum, mean, and standard deviation values, are presented in table 1.

COST FUNCTIONS

For each treatment, cost functions are presented in the following discussion. The cost functions are compared with the data used in derivation. The residuals as a percent of the range in observed costs, standard errors of prediction, and equation R^2 values are presented for each equation discussed (table 2).

[1]The C_p *statistic is a measure of the sum of the squared biases plus the squared random errors for the proposed regression at all data points. For an equation with negligible bias the* C_p *value is equal to the number of terms in the equation (Daniel and Wood 1971).*

[2]*The interactive regression program used was MULTREG, developed at the University of Minnesota School of Applied Statistics by Asst. Prof. Sanford Weisberg.*

ble 1.— Description of basic data used in developing cost equations for six stand establishment, release, and thinning site treatment activities in the Lake States

e atment	Number of projects	Size of area				Number of trees				Basal area removed			
		Mini-mum	Maxi-mum	Mean	Standard deviation	Mini-mum	Maxi-mum	Mean	Standard deviation	Mini-mum	Maxi-mum	Mean	Standard deviation
		(Acres)				(1000/acre)				(sq.ft./acre)			
nd plant	43	2	50	10.5	9.4	0.47	1.5	0.94	0.17	–			
chine site-preparation	28	2	118	27.5	28.8	–	–	–	–	–			
ial spray	36	4	276	53.0	63.9	–	–	–	–	–			
scribe burn	25	3	140	20.4	22.4	–	–	–	–	–			
nual release	16	10	320	67.0	53.0	–	–	–	–	10	28	18.7	5.7
n	38	8	250	52.4	47.0	–	–	–	–	20	70	38.0	10.5

ble 2.— Summary of cost equation statistics

e atment	Residuals as percent of range in observed costs			Standard errors of pred. over range of observed cost			Square root of residual mean square	R^2
	Minimum	Maximum	Average	Minimum	Maximum	Average		
	(Percent)			(Dollars)				
nd planting	0.13	12.0	3.0	232	278	237	229.10	0.93
chine site preparation	0.26	16.0	4.0	269	304	276	262.16	.96
ial spray	0.07	12.0	3.0	116	135	118	124.58	.95
scribed burning	0.32	40.0	9.0	105	136	110	102.05	.79
nual release	3.70	33.0	12.0	427	474	438	415.35	.87
nning	0.62	7.0	3.0	191	209	194	188.50	.82

1. Hand planting

$$Y = 43.82 + [41.298 + 0.050894(TPA)]\ AC$$

Costs included are labor, supervision, planting ock, and transportation. The range in observed sts was $4860, with a minimum observation of 40 and a maximum of $5000. The maximum sidual (observed minus predicted) was within 12 rcent of the range in cost. Standard errors of ediction averaged $237 over the observed range cost, ranging from $232 to $278. Using two andard errors as a guide to confidence, on the verage, the cost function can be expected to esti- ate true project cost within $474. Data was taken om 43 projects carried out in Minnesota. Fixed arges are $44 per project. Variable costs are $41 r acre and $51 per thousand trees planted per re. Equation R^2 is 0.93. To better illustrate the nge of costs, total costs and cost per acre for rious sized projects have been graphed from this uation for planting 500 and 1,000 trees per acre g. 1). These indicate that costs per acre for hand anting are relatively constant for areas larger an 10 to 20 acres in size.

2. Machine site preparation.

$$Y = 86.50 + [33.910 - 7.068(OP)]\ AC$$

Costs included are labor, supervision, transportation, fuel and associated equipment operation costs directly attributable to the project. The range in observed costs was $4,650 with a minimum cost of $47 and a maximum of $4,701. The maximum residual was within 16 percent of the range in cost. Standard errors of prediction averaged $276 over the range in observed costs, ranging from $232 to $278. The cost function on the average, can be expected to estimate project cost within $552. Data was taken from 28 projects in Minnesota. Fixed charges are $86 per project. Variable costs are $34 per acre ±$7 per acre depending on whether it is a machine pushing (−$7) or machine pulling (+$7) operation. Use of this term (OP) serves to distinguish between the differences in work the machine must perform. Equation R^2 is 0.96. The predicted cost per acre increased sharply for projects less than 20 acres in size (fig. 2).

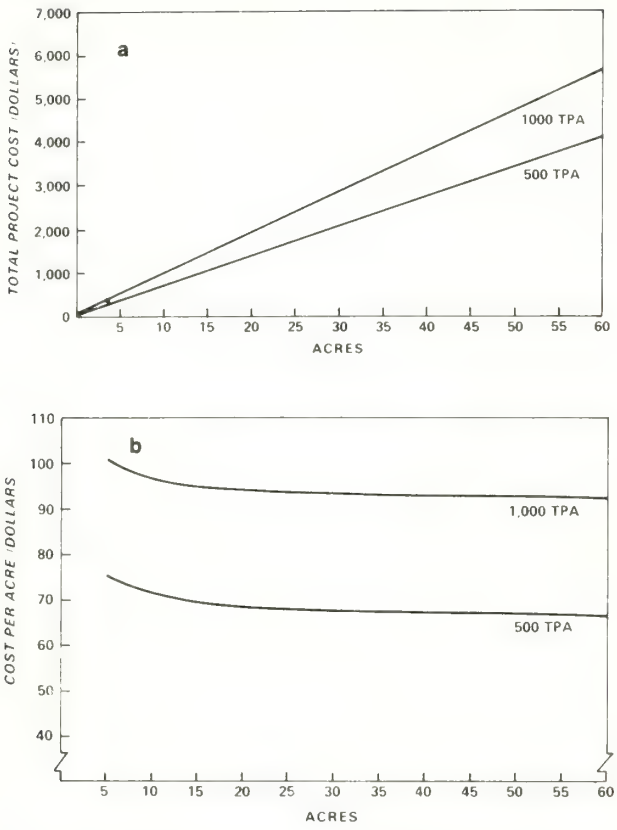


Figure 1.— *Cost of hand planting in the Lake States by size of planting area, 1976.*

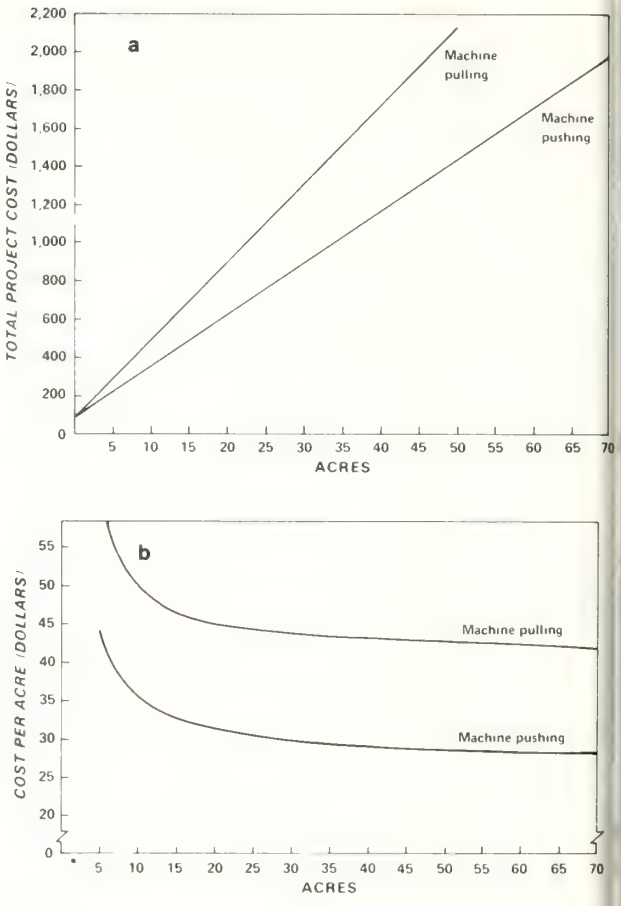


Figure 2.— *Cost of machine site preparation in the Lake States by pushing and pulling operations by size of project areas, 1976.*

3. Aerial spray.

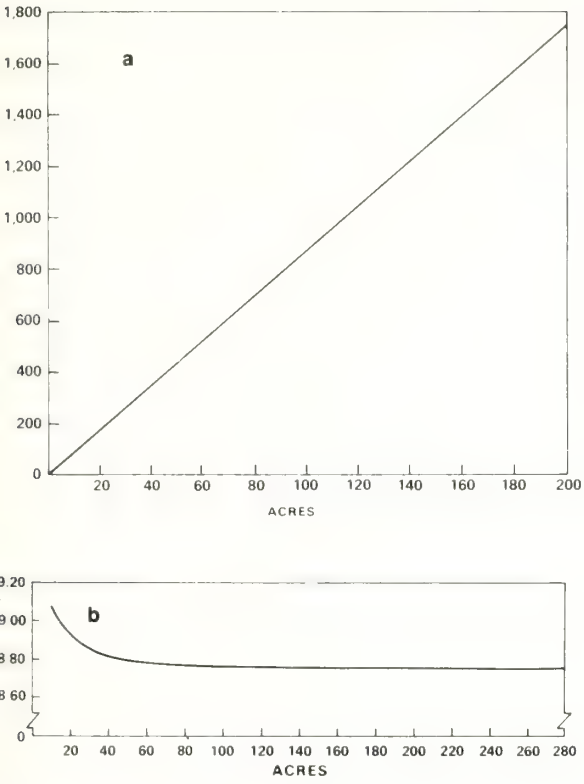
$$Y = 3.43 + 8.734\ (AC)$$

Costs included are supervision, labor, chemical cost, fuel cost, aircraft rental, and the cost of a pilot. The range in observed cost was $2,573, with a minimum observation of $74 and a maximum of $2,647. The maximum residual was within 12 percent of the range in cost. Standard errors of prediction averaged $118 over the range in observed costs, ranging from $116 to $135. The cost function, on the average, can be expected to estimate true project cost within $236. Data was taken from 36 projects in Minnesota. Fixed charges are $3 per project and variable costs are $9 per acre. Equation R^2 is 0.95. The predicted cost per acre increases sharply for projects less than about 40 acres in size (fig. 3).

4. Prescribed burning

$$Y = 0.69 + [23.824 - 0.499(AC) + 0.0038(AC^2)]\ AC$$

Costs included are supervision, labor, fuel, equipment and machine charges directly attributable to the project, and transportation. The range in observed costs was $703, with a minimum of $67, and a maximum of $770. The largest residual fell within 40 percent of the range in costs. Standard errors of prediction averaged $110 over the observed range in cost, ranging from $105 to $136. The cost function, on the average, can be expected to estimate true project cost within $220. Fixed charges of −$.69 would indicate that no fixed costs were included in the sample. As burning projects were carried out by agency personnel instead of contractors, the lack of a fixed charge per project



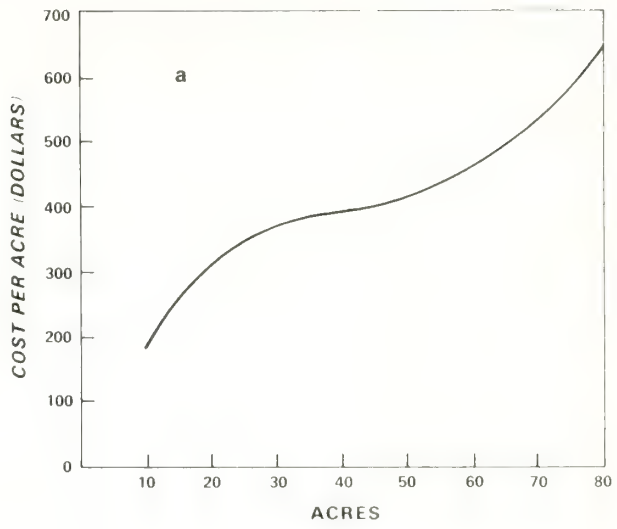
gure 3.— *Cost of aerial spraying in the Lake States by size of project area, 1976.*

ems plausible. Variable costs are $24 per acre, th an additional charge of −$.50 per square of oject size, and $.004 per cube of project size. uation R^2 is 0.79. The data indicate that cost per re for prescribed burning is strongly affected by e of project area, and is lowest when the area to burned is about 60 acres (fig. 4).

5. Manual release

$$Y = 73.36 + [.948(BAR)]\ AC$$

Costs included are supervision, labor, chemis, and transportation. The range in observed sts was $2,660, with a minimum of $274 and a aximum of $2,932. The largest residual fell thin 33 percent of this range. Standard errors of ediction averaged $438, ranging from $427 to 74. On the average, the cost function can be pected to estimate true project cost within $876. ked charges are $74 and variable costs are $.95 r square foot of basal area removed per acre. uation R^2 is 0.87. Costs per acre for manual ease increase rapidly for areas less than about acres in size (fig. 5).



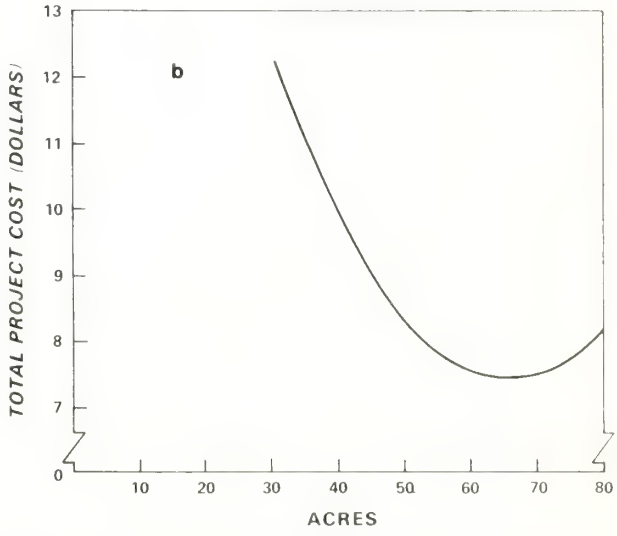


Figure 4.— *Cost of prescribed burning on level ground in the Lake States by size of project area, 1976.*

6. Thinning

$$Y = 120.29 + [0.418(BAR)]\ AC$$

Costs included are supervision, labor, transportation, and fuel and oil for chainsaws. The range in observed costs was $5,258. The largest residual was within 7 percent of the range in costs. Standard errors of prediction averaged $202 over the range in observed costs, varying from $191 to $209. Most of the time, cost estimates derived from this function can be expected to be within $404 of the true project cost. Fixed charges are $120, and variable charges per acre are $.42 per square foot

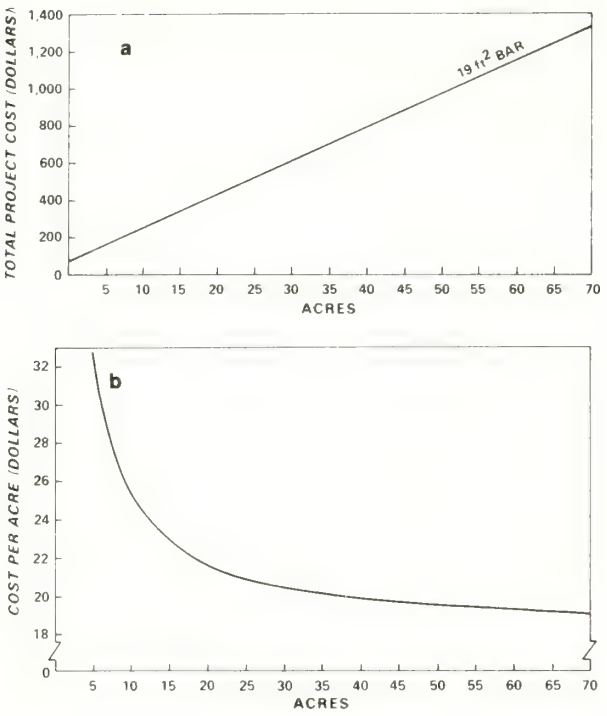


Figure 5.— *Cost of manual release in the Lake States for 19 square feet of basal area removed per acre (the mean for the observations) by size of project area, 1976.*

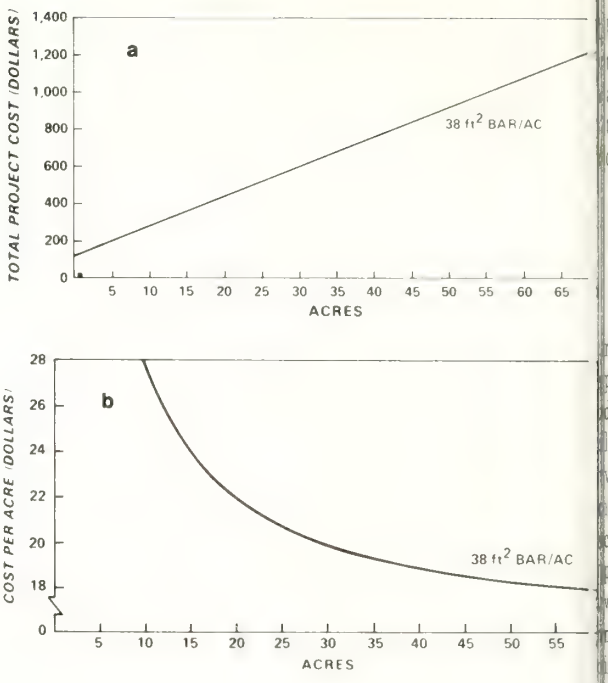


Figure 6.— *Cost of manual thinning in the Lak States for 38 square feet of basal area remove per acre (the mean for the observations) by siz of project area, 1976.*

of basal area removed. Equation R^2 is 0.82. Figure 6 presents a plot of the predicted values over the range of data.

DISCUSSION

Cost equations that may be used to estimate costs of proposed forest treatment projects have been developed from records of actual projects. To illustrate, assume a hand planting project is proposed. Seven-hundred fifty trees per acre will be planted on 40 acres. The equation is:

$$Y = 43.82 + [41.298 + 0.050894(TPA)]\ AC$$

Putting in the trees per acre and number of acres to plant, the cost is:

$$Y = 43.82 + [41.298 + 0.050894(750)]\ 40$$
$$Y = \$3223$$

Dividing the estimated total project cost of $3,223 by the number of acres in the project (40) gives a per acre cost of $80.56. The true project cost, however, may differ to some extent from the estimate. Based on the average standard error of predictio the true project cost most of the time will not diff from the estimate by more than $474, or 15 percer of the estimated cost.

The cost estimators were derived from records o projects conducted during 1976; the predicted cost then, are in terms of 1976 dollars. As time pr ceeds, the estimates from these equations must b adjusted to account for the effect of inflation. Thi adjustment is most easily achieved by substitutin the estimated project cost into the compounde single payment formula, using the inflation rat as i, as shown below:

$$V_n = V_o\ (1 + i)^n$$

where:

V_n = future value
V_o = value estimated from 1976 cost function
i = inflation rate as a decimal
n = numbers of years since 1976

nless technological changes occur that alter the pe of systems used and the relation between cost nd the independent variables presented earlier, ie above adjustment provides a simple means of etermining the future costs of projects.

CONCLUSIONS

Six equations were derived from existing project ecords. The equations allow estimation of total oject cost for certain forest treatments. Confi- ence in estimates obtained from the equations is mited to two prediction standard errors. High R^2 alues were obtained for each equation presented, dicating that the independent variables in- uded in an equation are useful predictors of total oject cost. The order of R^2 values was logical, ith the highest R^2 terms being obtained for the ost highly mechanized projects. The more labor- tensive projects were found to have lower R^2 rms. Fixed and variable costs could be identified om the equations. The equations presented ap- ear to be reasonable predictors of cost for the ake States.

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SEGREGATING WOOD AND BARK CHIPS BY PHOTOSORTING

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SEGREGATING WOOD AND BARK CHIPS BY PHOTOSORTING

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Houghton, Michigan

Bark, foliage, and dirt have prevented the videspread use of whole-tree chips in the pulp nd paper industry. A chip debarking process as already been developed by the Forest Engineering Laboratory, North Central Forest Experiment Station (Arola *et al.* 1976), and as been installed in a production-scale pilot lant in New Brunswick, Canada (Wawer and Misra 1977). A "scalping" or presorting proc-ss could first remove a "clean fraction" of hips and reject fractions with much bark, hus reducing the amount of material proc-ssed by compression debarking. Such resorting would reduce the size of the com-ression debarking system and in turn reduce he overall capital investment needed.

Sorting processes based on differences in ptical properties, particularly color or spec-ral characteristics, have been used for vari-us agricultural commodities (Bilanski and Fisher 1976, Chamberlin 1976, Massie and Norris 1975, Rohrbach *et al.* 1973, Worthing-on *et al.* 1973). Most of these systems segre-ate on the basis of spectral reflectance neasurement, i.e., surface color. Due to the resence of bark/wood chips (bark attached to wood chip) during the dormant season and roblems caused by the variation in surface olors of bark and wood, the transmittance of ight through wood and bark chips was inves-igated rather than reflectance. The purpose f this paper is to show that bark and wood hips differ sufficiently in their optical ransmittance to be sortable, and to present reliminary results of an experimental sort-ng system based on this difference.

SPECTRAL MEASUREMENTS

The average spectral transmittance of bark and wood chips was measured for several species using a Gamma Scientific[1] scanning spectral radiometer. This instrument consists of a model 700-31 grating monochromator and a model 2900 auto-photometer which uses a photomultiplier tube (PMT) as a detector. Wood and bark chips were placed over the entrance aperture of the monochromator (fig. 1), and the relative spectral transmittance was measured at each of seven equally spaced wave lengths from 500 to 800 nanometers (nm). This range is from the green to the near infrared regions, respectively. The data for ten randomly selected wood and bark samples from the ⅝-inch size chip fraction (chips which have passed through a screen with 1⅛-inch diameter holes and were retained on a screen with ⅝-inch holes) were averaged logarithmically. Logarithmic averaging was chosen because chip transmittance varies exponentially with chip thickness. The average spectral transmittance curves are shown for aspen, maple, and loblolly pine in figures 2, 3, and 4, respectively.

After obtaining the average transmittance for both wood and bark chips for each species, the ratio of average wood transmittance to average bark transmittance was calculated at each of the seven wavelengths to obtain

[1]Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.

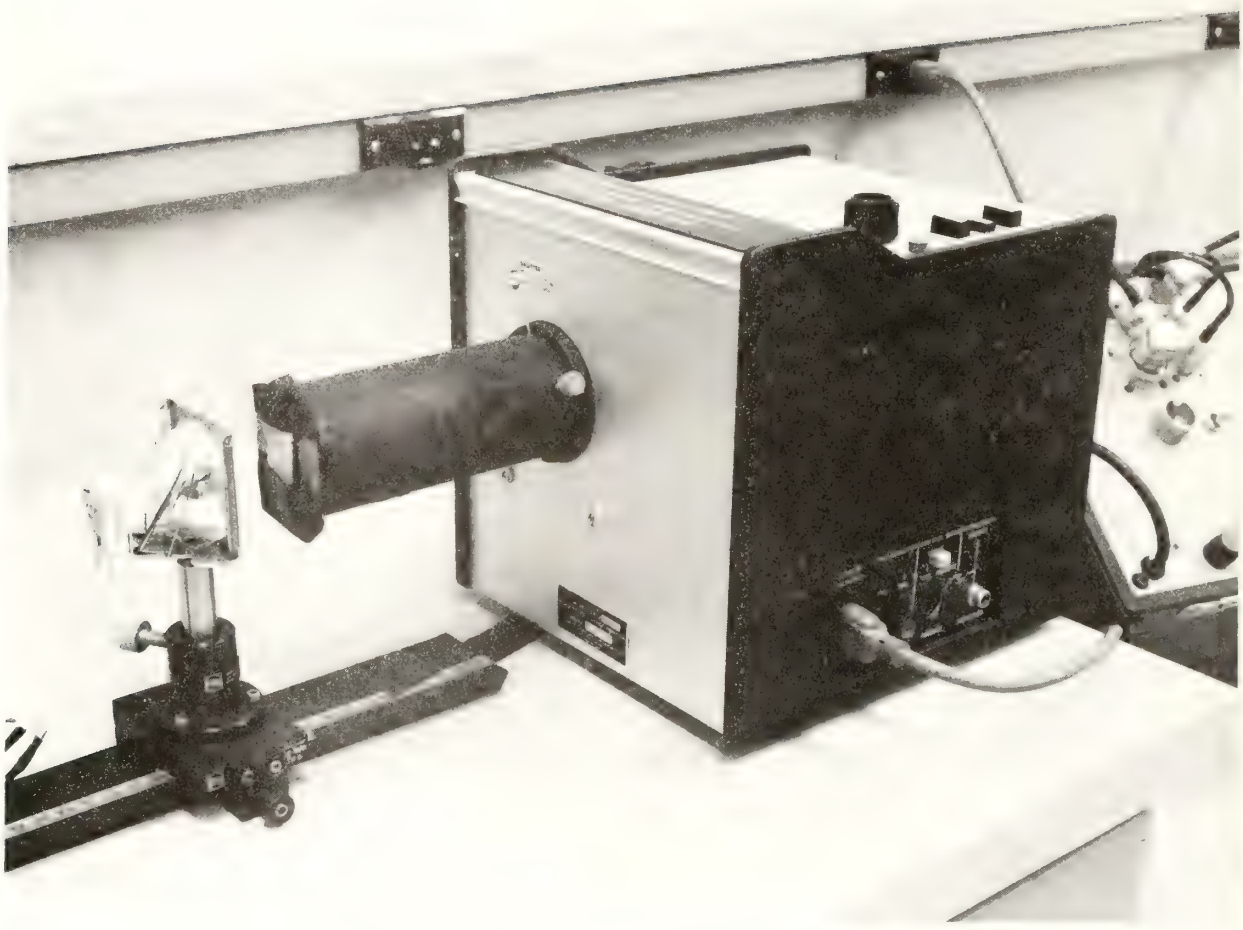

Figure 1.—*Monochromator used to measure the spectral transmittance of the chips.*

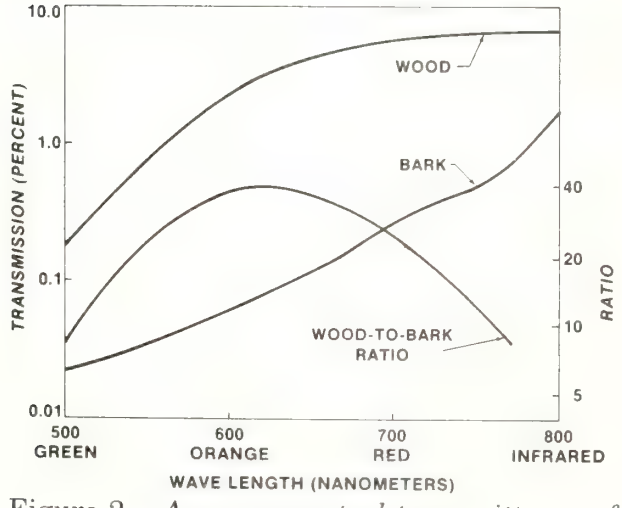

Figure 2.—*Average spectral transmittance of aspen chips.*

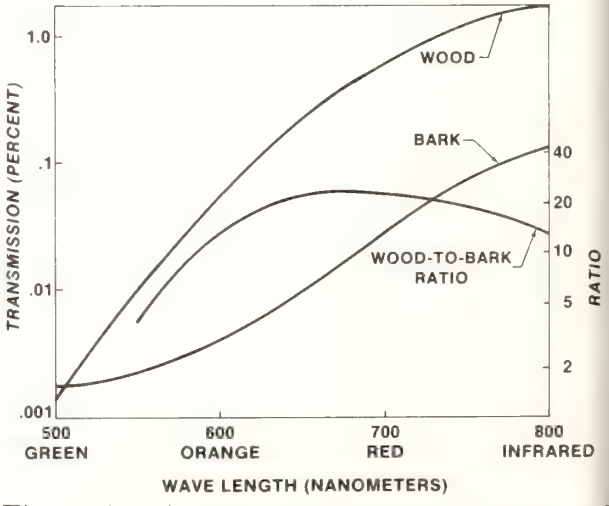

Figure 3.—*Average spectral transmittance of maple chips.*

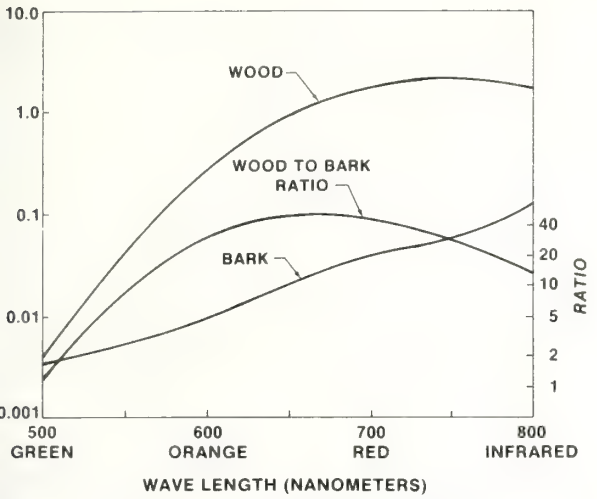

Figure 4.—*Average spectral transmittance of loblolly pine chips.*

urves (figs. 2, 3, and 4). These curves are seful in determining the optimum spectral egion for differentiating between bark and vood chips. The same or greater differences vere also obtained between the wood and ark chips of sweet gum and hickory.

The wood-to-bark ratio curves for the spe-ies measured have all peaked within the in-erval 600 to 700 nm. This indicates that the nost reliable segregation of chips would occur vhen the response peak of the source-detector ystem also lies in the 600- to 700-nm region. While a PMT was used to gather basic data on he chip spectral characteristics, the actual orting system uses silicon phototransistors o detect the light transmitted through the hips from the incandescent source. The sili-on detector spectral response curve peaks at 00 nm with the 50 percent relative response oints being located at 500 and 1,000 nm.

The spectrum of a typical incandescent amp is very broad compared with the silicon etectors, peaking in the neighborhood of ,000 nm. The overall spectral response is thus etermined primarily by the silicon detectors f no auxiliary filters are used. Spectral opti-nization with filters has not been attempted s the slight discrimination improvement vould be more than offset by the correspond-ng light level increases that would be needed.

EXPERIMENTAL PHOTOSORTER

As implied by the graphical data in figures 2, 3, and 4, bark and wood chips from some species can be readily differentiated from one another on the basis of their optical transmittance. A block diagram of the system used to sort the chips is shown in figure 5. The chips are fed by a conveyor over a linear array of optical detectors (silicon phototransistors). Light from an incandescent source is incident on the chips from above. The light intensity is adjusted such that most wood chips transmit sufficient light to be sensed by the detector array; thus the detectors "see through" the wood chips. When a bark chip passes over the detectors, however, the transmitted light falls below a preset detection threshold and the detector photocurrent decreases. The resulting signal is amplified to energize an air valve, deflecting the bark chip with a blast of air.

The mechanical arrangement used is shown in figure 6. An incandescent quartz-halogen slide projector lamp (type ELB, 30V, 80W) is used as a light source. It is focused into a line image aligned with the detector array by a cylindrical lens. The detector array consists of silicon phototransistors spaced on 0.1-inch centers (Fairchild FPA 700A) in a molded opaque epoxy module with clear windows. Each detector module contains nine separate phototransistors.

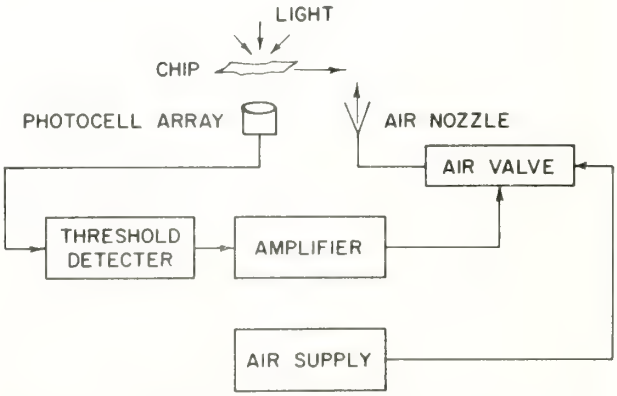

Figure 5.—*Block diagram of the sorting system.*

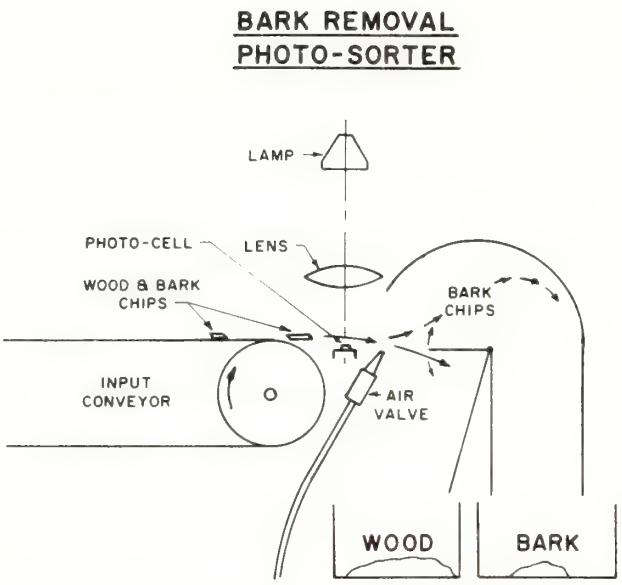

Figure 6.—*Mechanical configuration of the sorting system.*

The location of both the sensor array and the air valve nozzles must be carefully considered. The optimum sensor location is determined with respect to the free-flight trajectories of the chips as they leave the end of the conveyor. If the detectors are too low, small bark chips will not be reliably detected because of the excessive light passing around the chips and striking the detectors. On the other hand, it is undesirable to have the chips actually slide aross the windows of the detectors as the windows can erode rapidly under such conditions. Therefore, the detectors should be as close to the chip trajectory as possible without actually touching the chips.

The conveyor belt speed and the mechanical and inductive delay in the valve must be taken into account in selecting the optimum air nozzle location. A brief air pulse caused by a small bark chip must intercept the chip as it continues along its free-flight path. For a belt speed of 400 feet per minute (12.5 milliseconds per inch) and a valve turn-on delay of about 6 milliseconds, the optimum location for the nozzles is about 0.5 inch from the sensors.

The pilot system contains a detector array 9.9 inches long consisting of eleven detector modules (fig. 7). Each module has a separate threshold detector, amplifier, and air valve associated with it. Each air nozzle is aligned

Figure 7.—*Pilot model of photosorter system. The electronic portions of the system are not shown.*

with the center of its corresponding detector module. The circuit is designed such that the air in a given nozzle is turned on if the illumination level on any one (or more) of the detector cells in the corresponding module falls below a preset threshold value. The detectors are illuminated in the pilot system by three lamp/lens pairs.

The detectors within each module are matched for sensitivity; the variation from one module to another is much larger and must be compensated for, however. Compensation is also required for variations in the brightness of the light incident on the phototransistors. Good matching of the sensitivity across the entire detector array is achieved by initially adjusting the detection threshold of each channel separately. The equivalent detection threshold level of the entire system can then be scaled up or down by varying the intensity of the lamps (by changing the filament current). This permits optimizing the system for different species without separately adjusting each channel again.

RESULTS AND DISCUSSION

Preliminary results for ⅝-inch aspen chips ere obtained by passing the chips over the notosorter, giving "accept" and "reject" fracons (table 1). Included are results for four fferent light levels that ranged from 2.5 to 5 milliwatts per square centimeter. The reults indicate that a compromise has to be ade between wood recovery and the bark ntent of the accepts. At the lowest light lev- the accepts had a bark content of 1.4 percent nd contained 70 percent of the wood, whereas e highest light level gave 5.1 percent bark the accepts and 96 percent wood recovery. In a production process the photosorting ould be a first stage "scalping" or presorting rocess where the accepts obtained are suitae for pulping and the rejects would be beneciated further. Using the results obtained at the 2.5 milliwatts per square centimeter light level (table 1), 63 percent of the input material would be recovered as clean fiber and 37 percent would be conveyed to another process such as compression debarking. The accepts and rejects from each chip size fraction (possibly two or three fractions) would be combined to form one accept and one reject fractions. Instead of processing the photosorter rejects by a second method, an alternative would be to recover 60 to 80 percent of the material as clean chips and use the rejects for fuel.

The photosorting technique can also be used as a quality-control system to monitor the relative bark content of a chip mixture. The manual sampling and counting process presently used could be eliminated, and more frequent sampling of the chip mixture would be feasible. Such an application would entail optically counting the total number of chips as well as the number of bark chips. Increased sorting accuracy could be achieved in a quality-control system because more time could be allocated for measuring each chip than could be tolerated in a production-oriented sorting system. Utilizing a microprocessor to perform the required logical and arithmetical operations would then be possible; this would permit a direct readout of the bark chip percentage.

able 1—*Effect of light level on photosorting -inch aspen wood and bark chips*[1]

(In percent)

oduct	Bark content	Portion of total chips	Portion of total wood	Portion of total bark
LIGHT LEVEL[2]-2.5 mW/cm²				
out	10.6	100	100	100
Accepts	1.4	63	70	8
Rejects	26.2	37	30	92
LIGHT LEVEL—3.3 mW/cm²				
out	9.3	100	100	100
Accepts	2.3	79	86	19
Rejects	36.7	21	14	81
LIGHT LEVEL—4.3 mW/cm²				
out	8.9	100	100	100
Accepts	3.3	88	93	32
Rejects	48.5	12	7	68
LIGHT LEVEL—5.5 mW/cm²				
out	9.7	100	100	100
Accepts	5.1	91	96	48
Rejects	56.4	9	4	52

hips passed through a 1⅛-inch perforated screen and were retained on ⅝-inch screen. Moisture content of the chips ranged from 49.4 to 50.8 rcent (wet basis). The sorting was conducted at a feed rate of 1 /hour/foot of belt width.

he light level was measured with a United Detector Technology Model X optometer through a 0.252-cm (0.099-inch) diameter aperture. This trument uses a silicon detector that does not respond to wavelengths ger than 1 μm. Since incandescent lamps produce a substantial quantity nfrared radiation (with a wavelength >1 μm.), the true total irradiance els would be somewhat higher than the values given above.

SUMMARY

The average optical densities for bark and wood chips for some species are sufficiently different to permit segregating the chips on this basis. The peak wood-to-bark transmission ratio is typically in the range from 10 to 50.

Preliminary segregation results indicate that 70 to 80 percent of the wood fiber can be recovered with less than 2 percent bark content. The segregation threshold is continuously variable and can be readily altered to accommodate different species or use requirements. The optical and electronic components are readily adaptable to a variety of desired system sizes, configurations, and feed mechanisms.

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Spectral transmittance measurements on aspen, sugar maple, and loblolly pine wood and bark chips resulted in peak wood-to-bark transmission ratio ranges from 10 to 50. Preliminary segregation results from an experimental photosorter indicate that 70 to 80 percent of the wood fiber can be recovered with less than a 2 percent bark content.

OXFORD: 361.0:825.73:U535.3. KEY WORDS: Chip quality, whole-treechips, pulpwood, optical density, spectral transmittance.

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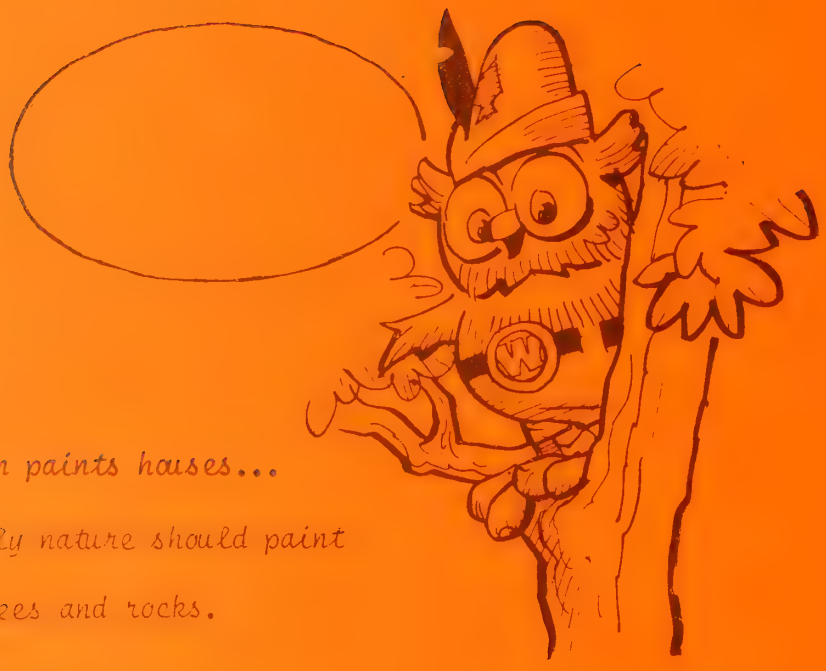

Man paints houses...

only nature should paint

trees and rocks.

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TAXATION OF FOREST AND ASSOCIATED LAND IN ILLINOIS

David C. Baumgartner and Ronald I. Beazley

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TAXATION OF FOREST AND ASSOCIATED LAND IN ILLINOIS

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uring the 1960's, a series of forest taxation ies was conducted by graduate students in stry and economics at Southern Illinois Uni- ity at Carbondale under the direction of Dr. ald Beazley. Nacker (1967) studied the admin- tion and burden of property taxes on forest associated land in southern Illinois. He also loped and tested a model for predicting forest associated land values from published data. man (1970) refined this model while investi- ng the feasibility of statistically predicting st and associated land values and developing value maps that would be useful in assess- t. Baumgartner (1972) considered the Illinois erty tax situation in light of forest and associ- land owner objectives and behavior.

mbined with other information obtained from l, private woodland owner research in Illinois elsewhere, these studies provide a fairly com- picture of forest and associated land taxation inois. In view of an increasing interest in tax stments as an incentive to improve woodland nd management (reflected in current legisla- proposals) it seems appropriate to review the ngs of these studies.

DEPARTURES FROM CONVENTIONAL FOREST TAX PROBLEM APPROACHES

l of the above studies utilized the term "forest associated land" rather than "forest land" or dland". Beazley (1965) pointed out that when is concerned with all Illinois lands that are rdependent in the production of wood, recrea- esthetics, wildlife, erosion control, and water, oncept of forest land should include what he has termed "forest and associated land" (FAL).[1] This includes conventionally defined forest land, plus brush land, unimproved pasture, and much land on noncommercial farms. In other words, all nonurban, nontransportation or service, and noncommercial agricultural land. These lands are sufficiently similar to be considered as an entity for multiple-use, integrated land-use planning and management. Beazley estimated that roughly 9 million acres or 25 percent of the State land area is forest and associated land (FAL).[2] This is more than twice the conventionally defined forest land estimate of 10.5 percent of the State, and closely

[1]*Because "forest and associated land" is the subject of this paper and the term is used many times, we have resorted to the use of an abbreviation in the interest of brevity and simplicity.*

[2]*Beazley arrived at his estimate as follows: (1) The ratio of land in commercial farms to all land in all farms was first determined. Call it "R" (2) The following areas were summed: woodland, pastured and not pastured; other pasture, not cropland or improved pasture; and wasteland ("other land" less 2 percent of farm area for buildings and roads). Call this total "W". (3) An estimate of the acreage of actual commercial farm land in commercial farms was then determined by subtracting the proportional amount of "W". That is, commercial land =land in commercial farms $-(R \times W)$. (4) An estimate of urban, service, and transportation land (6 percent for the State) was added to commercial farm land to provide an estimate of "urban, service, and (genuinely) agricultural land". (5) The figure for urban, service, and agricultural land area was subtracted from the total land area in each case to arrive at the figure for area in forest and associated land.*

approximates the total of what assessors call "unimproved land", thus providing a useful frame of reference for taxation studies.

In many past forest land tax studies it was assumed that the land involved is clearly best suited for wood production and that it is owned and managed for this purpose. In Illinois and most of the Midwest, however, this assumption may be misleading for tax purposes. At best it would be true for only a few large tracts. Baumgartner evaluated the importance of the conventionally defined forest tax problems in Illinois, given the well documented fact that most forest land in Illinois is owned for a combination of uses. These include water and erosion control, recreation, rural residences, forage, and speculation. Marketing of timber products may, or may not be included.

RESULTS OF ILLINOIS TAXATION STUDIES

The Illinois Department of Revenue provides detailed maps and records to help assessors in the valuation of rural land in Illinois. Although the materials provided are generally much better suited to valuation of agricultural land, some guidelines are outlined for appraising land containing merchantable timber (Appendix I). However, Nacker (1967) found that assessor practice deviated considerably (particularly for FAL) both from Illinois statutory requirements and from recommendations of the Department of Revenue. Part of his study dealt specifically with the assessment of FAL. Assessors in the 17 southernmost counties of Illinois were interviewed using a questionnaire designed to obtain information on the characteristics of assessors, on how each administered his position, and on the techniques used in assessing FAL. Eighty-three of the 90 assessors in the study area were contacted. Nacker reported a large measure of assessor indifference to and noncompliance with Department of Revenue procedures. He found that 32 of the 83 assessors interviewed applied a flat rate valuation (10 of these would make an adjustment upon complaint or special circumstances) to all unimproved land in their taxing jurisdiction and another flat rate to all improved land. Twenty-eight of the 83 assessors admitted that they did no assessing, but merely copied the figures from the preceding assessment period. The remaining 23 assessors made some effort to obtain an individual value for each pa but only four came close to using the recommer Department of Revenue procedures. Only a assessors considered the value of standing tin at all in their valuations and none considered annual growth of trees.

Admittedly, strict adherence to Departmer Revenue criteria would not necessarily result greatly improved assessment of FAL values. standards that have been devised are strongl rected toward determining the potential of lar produce annual crops, and sales value is assu to be closely related to annual income-produ capacity. FAL values may have little correla with the land's potential to produce income f sales of wood.

In addition to providing information on the tivities of assessors, Nacker's work included computation of tax burdens for 314 land tran tions in southern Illinois. He found a highly sig icant inverse relation between tax burden and value. Thus, to the degree that FAL was low pri in southern Illinois, it appears it was over sessed compared with farmland, which, in gene is higher priced.

Both Nacker (1967) and Hickman (1970) u linear multiple regression analysis to deve FAL value prediction models. Sales value d were obtained from the county records of tran tions that took place during the years 1959-19 Both studies utilized the same sample un Nacker developed a list of 38 independent va bles thought to be related to sales value. Th variables (Appendix II) included measures of cessibility to urban areas, proximity to uni physical features, existing land-use patterns, others. He then derived a prediction equation each of the nine sample units, as well as for aggregate, showing those variables that cont uted significantly to variation in the depend variable (i.e., sales value). He was able to acco for significant amounts of sales value variati particularly within individual sample units (pendix III), and he concluded that even better p dictive models could be developed.

Hickman selected two of Nacker's more pron ing sample units and, using stepwise linear mu ple regression analysis, attempted to develo better predictive model. Using his new model, estimated sales values within a sample unit a

onstructed a value map identifying areas of ho-
nogeneous land values. He accounted for 70 per-
ent of the total variation in sales value in one of
is sample units and 52 percent in the other. How-
ver, he also found that the standard error of the
stimate and the standard errors of the partial
egression coefficients were large. In general, the
redictive models were inferior to assessor perfor-
nance. His value map did not show large areas of
niform value.

Hickman reasoned that the poor prediction was
ue to improvements (mainly buildings) on the
ale properties, the value of which he was able to
stimate only generally with available data. He
elt that the bare land rental value would be much
nore predictable and show larger homogeneous
reas of value.

Although the results of both Nacker's and Hick-
nan's work indicate that difficulties still remain
n constructing precise value prediction models,
ney do suggest that some combination of predic-
ive models, evidence of transactions, and good
ssessor performance could probably be more ac-
urate than any of the three individually.

EXISTENCE OF CONVENTIONALLY DEFINED FOREST TAXATION PROBLEMS IN ILLINOIS

Variable versus Fixed Tax

Many feel that a fixed tax is more favorable to
orestry (in that it does not affect the best combina-
ion of factors of production) than a variable one. A
xed tax would probably never be established by
aw, but could occur when assessor's valuations
ere copied from year to year and taxation rates
emained unchanged over long periods.

Much more concern has been shown for the vari-
ble nature of the tax in relation to tree value and
rowth than for the bare land component of the
roperty value. Owners, it is said, can reduce taxes
y liquidating trees, shortening rotations, and re-
ucing inputs that could increase tree values. In-
reases in bare land value could also encourage
epletion, but the bare land component of value
ould not easily be changed and the tax would be,
n this sense, fixed.

In Illinois, the calculation of separate value for trees is rare. It is doubtful that any assessors have ever computed, or even imputed, the value of the annual growth on the trees of Illinois land, even though a strict interpretation of Illinois' tax law would require that they do so. Because of the complexity of the measurements involved, there is little reason to expect practice to change in the near future.

Assessments and taxes on FAL in Illinois do, of course, change roughly in relation to land values, although far from consistently. The value of the trees growing on the land may, or may not, be generally considered by the assessor in arriving at the total value of a parcel of land.

In light of all this, owners could not reduce taxes by liquidating trees, shortening rotation periods, or reducing inputs for the production of any FAL outputs. If, however, the tax laws were rigidly enforced, a problem (at least a theoretical one) could exist for those owners having significant tree growth on their land.

Time Bias

A common forest taxation problem is that of "time bias". Unlike producers of other farm crops, who receive income annually, timber growers may have to wait several years (or decades) before selling a crop. Owners, who must meet annual tax payments are, in theory, encouraged to harvest prematurely. Some States have devised yield tax laws to reduce time bias. In these States, land remains subject to the annual property tax while trees are exempted until harvest.

To the extent that most assessors in Illinois ignore the value of the trees on a parcel of land there would be no time bias. Other assessors do, at least subjectively, include the value of the trees on a parcel of land in arriving at its value. Moreover, the land itself is taxed annually, so time bias could apply, at least partially, on all FAL in Illinois.

How important time bias is in a given area depends greatly on how many single-purpose owners are in that area. Time bias is usually associated with timber growers whose only income and reason for ownership are the production of timber. Illinois probably has no such owners. Most have other sources of income and only a few owners hold FAL primarily for commercial timber growing.

Alternative uses bring greater returns than single-purpose timber management for most Illinois FAL owners. A study in the early 1960's in Jackson County (a county with a high concentration of FAL) showed that only about one woodland owner in three received continuing income from wood products (Baumgartner 1963). The same study indicated that only 43 percent of woodland owners considered farming their major occupation. A 1970 study of new landowners in southern Illinois (Neuzil 1970) showed that only 36 percent were farmers.

Theoretically time bias may exist in Illinois, at least for the land component of FAL. But, the single-purpose ownership assumptions necessary to show the harmful effects of time bias on forestry are not reasonable in Illinois.

Although the problem of distinguishing between the capital investment and the return in forestry is often discussed independently in the forestry literature, it is little more than a specific example of time bias. Trees, it is said, are the return to an investment in forestry. Landowners, however, cannot take the return without taking the investment too. To tax 30-year-old trees at their current value is to tax all the value produced in 30 years. Each year the growth of all previous years is retaxed. However, as already discussed under time bias, when actual assessor behavior is examined, and the realism of single-purpose ownership assumptions is considered, no problem is apparent in Illinois.

Separating land and tree values is said to cause another forest property taxation problem. If land value were computed on the basis of expected future timber yields discounted to the present, a kind of double counting could occur. Timber as productive capital could be included in both the land and the timber components of value. Again, because assessors seldom consider the value of trees, no apparent problem exists along these lines for owners of FAL in Illinois.

The Amount of the Tax

The traditional procedure of relating property taxes to the wood-producing potential of a parcel of land has little relevance in Illinois. The potential rates of return from single-purpose woodland management in the midwest (Callahan 1966) are low and could be eliminated by even moderate property taxation. When the tax is as high as the property's net income before the tax, owners tend to abandon the land or find another use for it, after liquidating any merchantable timber. However no land has been abandoned or confiscated in Illinois since the early 1930's. Some FAL has been cleared for farming, but at the same time, other land is reverting to FAL. There seems to be little relation between trends in the price of FAL and the profitability of growing timber for sale in Illinois, even though both land prices and the prices of most primary wood products have gradually increased. Thus, it is obvious that if the sales price of land represents the sum of all future net revenues discounted to the present, then revenue (which may be intrinsic) other than income from wood products is involved. Much of this revenue cannot be measured in monetary terms nor on an annual basis.

Given that FAL values have little relation to timber growing potential, forest taxation problems involving time bias are not really pertinent in Illinois. Likewise, the often-suggested solutions to forest taxation problems, including yield taxes, deferred taxes, and taxes based on timber growing potential, offer little hope of encouraging Illinois FAL owners to make "desired" investments in their land. It is not surprising that these special taxes have had little acceptance and effectiveness where they have been used. Taxation problems involving the quality of assessment are, of course, relevant, and the modified tax laws, most of which resemble the "present use" taxes, deserve further attention.

IMPACT AND IMPORTANCE OF FOREST AND ASSOCIATED LAND TAXES IN ILLINOIS

It has been shown that assessment problems, including a consistent "parcel bias", exist for owners of FAL in Illinois. A "time bias" also exists for land (but not for growing stock) because the tax must be paid annually while income from sales of wood occurs at long intervals. Taxes on FAL are high compared with cropland in terms of income-producing capability. However, when the tax problems associated with time and productivity are

considered in the context of multipurpose ownership and the concept of FAL, they seem irrelevant in Illinois.

Impacts of the property tax on the management of FAL appear to have been minimal. In one Illinois study (Baumgartner 1976) 27 of 121 Jackson County woodland owners had some complaint apart from the standard one that taxes are too high. Of the 27, 17 felt that assessment was worse for woodland than for agricultural land. Six felt that the tax should be based on income or potential income from the woodland. Two expressed in vague terms that somehow the tax did not favor forestry. One felt that the tax should vary with what use is being made of the woodland, and one felt that there should be no tax at all on woodland. It is striking that nearly the whole range of conventionally defined forest property tax problems was expressed, but more important is the fact that only 20 percent of the owners expressed any concern at all, and this concern was primarily with inconsistent assessment.

This same study correlated the owners' attitude toward their woodland taxes and the per-acre woodland taxes themselves with 210 other forestry variables. Neither tax variable showed a high correlation (greater than r=0.25) with any of the other forestry variables. Tax levels or problems neither encouraged nor deterred woodland management.

The effects of the property tax or changes in it on owners of FAL are, of course, not uniform. Christmas tree growers (classic single-use owners) could experience conventionally defined tax problems and impacts. Other types of woodland owners would be affected differently by the tax.

Although the impacts of property taxes on FAL in Illinois do not appear to be large, improved assessment in terms of both uniformity and elimination of "parcel bias" would be a desirable first step in improving the tax.

SUMMARY AND CONCLUSIONS

The results of the Illinois FAL taxation studies can be summarized as follows:

(1) Assessment of forest and associated land was found to be generally poor and inconsistent.

(2) There was a highly significant tendency for low-value land to be assessed and taxed at higher rates than higher value land.

(3) Land value prediction models without on-site inspections and evidence of transactions appeared to offer only a partial solution to assessment problems.

(4) Conventionally defined forest taxation problems involving time bias were apparent for land but generally not for trees or for tree growth.

(5) The impacts of the ad valorem property tax on the ownership and the intensity of management of FAL did not appear to have been large.

These results do not indicate that conventional types of forest land property tax adjustments would provide incentive to more intensive FAL management in Illinois. The poor acceptance of optional forest tax plans in other States (Appendix IV) supports this conclusion. Smith (1965) also concluded that the most significant improvement in forest taxation in Missouri could be achieved through more accurate assessment.

Current interest in improving forest land taxation centers on "modified tax laws" most of which resemble present-use valuation and taxation laws. The experience of other States indicates that present-use tax laws have been fairly effective in preserving high quality farmland near developing areas that almost certainly would remain in agriculture under a comprehensive land-use plan. Even here their use appears to be primarily a tactic to delay development and allow time for more careful planning. Their present potential in Illinois for FAL would seem limited to providing such a delay in a fairly small area of rural-urban fringe situations.

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APPENDIX I

PROCEDURE FOR APPRAISAL OF MERCHANTABLE TIMBER

The following outlines the procedure for valuing merchantable timber. The base land value of merchantable timberland on any tract is determined by adding the value of merchantable timber to the base land capability value as described in the paragraphs on rural land valuation.

The general practice provides that merchantable timber is not valued separately unless such tracts have pole size and saw log size stands and are used exclusively for the growing of timber. Thus, young timberland or small windbreaks and cattle shelter timber tracts are not considered in valuing merchantable timber.

The value of merchantable timber depends on the kind and size of trees and the number of acres of such trees. While young timberland containing small growing trees has some value separable from the land, such value cannot be realized without reducing the productive value of the timberland. Therefore, the smaller trees should be included in the valuation of the land, and a separate value should be added only for pole size and saw log stands of merchantable timber.

Following are the main steps for the appraisal o such merchantable timber:

1. Determine the approximate number of acre covered with merchantable timber. Aeria photographs, in addition to field checks, fur nish this information and the use of a plani meter or grid gives the number of acres.
2. Estimate the number of pole size and saw log trees on each acre of the tract. Again the aerial photograph and the field inspection assist in furnishing information on the number of acres of such mature trees.
3. Multiply the total number of acres having such merchantable timber on the tract by the average value per acre. The average value per acre is estimated according to the quality and average number of pole size and saw log tree per acre.
4. Add the total value of the merchantable timber on the tract to the base land capability value to obtain the total land value of the tract.

The Illinois Department of Revenue will give necessary technical assistance on the valuation of merchantable timber, when requested by the assessing official.

APPENDIX II

NACKER'S ORIGINAL PREDICTIVE MODEL

eneral formulation of predictive model:

$X_1 = b_0 + b_2X_2 + b_3X_3, \ldots, b_{39}X_{39}$

here:

X_1 = sales value/acre (market value) (nearest dollar)
X_2 = size of sale (acres)
X_3 = date of sale (coded 1-14)
X_4 = tax rate, year of sale
X_5 = assessed unimproved acreage/sale (percent)
X_6 = assessed value of improvements, year of sale (nearest dollar)
X_7 = assessed unimproved acreage/sale (acres)
X_8 = improvements, year of sale (yes=1, no=0)
X_9 = F_1 acreage (80 to 100 percent forested) (acres)
X_{10} = F_2 acreage (50 to 80 percent forested) (acres)
X_{11} = F_0 acreage (30 to 50 percent forested) (acres)
X_{13} = F_r acreage (less than 30 percent forested) (acres)
X_{14} = land resource type A (coded)
X_{15} = land resource type B (coded)
X_{16} = assessment ratio
X_{17} = tax burden
X_{18} = owners with same last name (yes=0, no=1).
X_{19} = number of ponds/sale
X_{20} = distance to the nearest gravel road (tenths of miles)
X_{21} = distance to the nearest hardtop road (tenths of miles)
X_{22} = distance to the nearest State or federal highway (tenths of miles)
X_{23} = distance to nearest town (miles)
X_{24} = proximity to water bodies of 40 to 800 acres in size (precision of 5 miles)
X_{25} = proximity to the Ohio or Mississippi Rivers (precision of 5 miles)
X_{26} = proximity to the Crab Orchard complex (precision of 5 miles)
X_{27} = total recreation resource acreage by county (percent)
X_{28} = Shawnee National Forest acreage by county (percent)
X_{29} = forested land acreage by county (percent)
X_{30} = forest and associated land acreage by county (percent)
X_{31} = proximity to urban places of 100,000 population or more (precision of 5 miles)
X_{32} = proximity to urban places of 10,000 to 50,000 population (precision of 5 miles)
X_{33} = total population/county (person/square mile)
X_{34} = county acreage in farms (percent)
X_{35} = mean individual income/county: 1959 (dollars)
X_{36} = assessed net worth of county: 1960 (dollars/acre)
X_{37} = total acreage/county (acres)
X_{38} = commission or township county (comm.=0, twp.=1)
X_{39} = urban population, by county (percent)

APPENDIX III
RESULTS OF INITIAL NACKER MODEL

Unit of analysis	n	R^2	Signi-ficance level	[1]Adjus R^2
Total enumeration	364	0.3007	0.01	0.219
Sample unit:				
1	63	.4537	.01	.414
2	36	.7389	.01	.702
3	49	.7162	.01	.569
4	83	.5367	.01	.391
5	31	.6923	.01	.818
6	36	.6583	.01	.650
7	13	.6826	.05	.013
8	53	.6826	.01	.499
9	30	.7206	.01	.654

[1]The Adjusted R2 shows the coefficient of determination with the contributions of tax related variables taken out.

APPENDIX IV
APPLICATION[1] OF OPTIONAL STATE FOREST TAX LAWS

State	Enacted	Area to which law applied[2] 1956	Area to which law applied[2] 1967	Area of commercial forest land in private ownership, 1963	in private ownership classified under optional laws, 1967
		Acres			Percent
EXEMPTION AND REBATE					
Delaware	1931	0	0	382,000	—
Hawaii	1903	(3)	27,285	593,000	4.6
Maine	1872	(4)	2,300	16,964,000	(5)
New Hampshire	1903	(4)	(3)	4,210,000	—
Puerto Rico	1930	670	670	500,000	0.1
Rhode Island	1878	(4)	300	404,000	0.1
MODIFIED PROPERTY TAX					
Modified Assessment					
Connecticut	1963	—	48,363	1,818,000	2.7
Hawaii	1961	—	0	593,000	—
Indiana	1921	172,950	257,250	3,666,000	7.0
Iowa	1906	85,864	93,155	2,558,000	3.6
Maryland	1963	—	242	2,683,000	(5)
New Jersey	1964	—	(3)	1,866,000	—
Oregon					
Western Oregon Small tract optional Tax	1961	—	50,000	10,311,000	0.5
Pennsylvania	1965	—	(3)	11,789,000	—
Puerto Rico	1925	0	0	500,000	—
Modified Rate					
Minnesota					
Tree Growth Tax Law	1957	—	287,977	7,523,000	3.8
North Dakota	1967	—	[6]0	296,000	—
Ohio	1925	98,939	235,753	4,761,000	5.0
Wisconsin	1953	29,547	133,809	10,330,000	1.3
Deferred Payment					
Washington	1941	0	0	9,151,000	
YIELD TAX					
Alabama	1923	44,680	5,000	20,741,000	(5)
Connecticut	1913	1,093	24,745	1,818,000	1.4
Hawaii	1963	—	0	593,000	—
Idaho	1929	156,958	144,001	3,066,000	4.7
Louisiana	1910	380,979	[7]451,000	15,627,000	2.9
Massachusetts	1914	[8]56,530	(3)	2,860,000	—
Michigan					
Commercial forests	1925	301,212	630,000	12,801,000	4.9
Woodlots	1917	(4)	(4)	—	
Minnesota	1927	220,196	269,544	7,523,000	3.6
Missouri	1946	301,075	517,637	13,392,000	3.9
New York	1926	38,867	265,292	11,107,000	2.4
Oregon					
Forest Fee & Yield Tax	1929	968,716	995,346	10,311,000	9.7
Washington	1931	479,310	541,014	9,151,000	5.9
Wisconsin	1927	333,536	576,673	10,330,000	5.6

Source: Williams (1967). State Forest Tax Law Digest. p. 7.
Source: State Foresters and State Tax Commissions.
Not available.
"Very small".
Less than 0.1.
Contracts not effective until January 1, 1968.
1965
139 of 355 towns (1950).

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Baumgartner, David C., and Ronald I. Beazley.
1979. Taxation of forest and associated land in Illinois. U.S. Dep. Agric. For. Serv., Res. Pap. NC-165, 9 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Analyzes the operation and impact of the property tax on forest and associated land in Illinois and evaluates the potential of adjustments in the tax as an incentive to better management of forest and associated land.

OXFORD: 95(773). KEY WORDS: Property tax, valuation, assessment, yield tax, "time bias".

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Estimating Site Potential from the Early Height Growth of **Red Pine** in the Lake States

David H. Alban

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1979

ESTIMATING SITE POTENTIAL FROM THE EARLY HEIGHT GROWTH OF RED PINE IN THE LAKE STATES

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Grand Rapids, Minnesota

Foresters need site productivity information to nake good management decisions. Site index is ne most frequently used indicator of site productivity in the United States (Carmean 1975), nd most yield tables are based on site index vales. When stands are too young to measure site ndex by the conventional height-age approach, arly height growth can be a useful estimater of ite index. Wakeley and Marrero (1958) were the rst to use the growth intercept approach. They ound that for southern pines the length of 5 internodes (the growth intercept) beginning at the first horl below breast height was closely related to otal tree height. Others have since found a relaion between the growth intercept and site index or *Pinus Strobus* L. (eastern white pine) (Beck 971), *Pinus ponderosa* Laws. (ponderosa pine) Oliver 1972), and *Pseudotsuga menziesii* (Mirb.) ranco (Douglas-fir) (Warrack and Fraser 1955). Growth intercept of young Pinus resinosa Ait. (red ine) plantations was found to be closely related to ubsequent height growth in New York (Ferree *et l.* 1958) and to site index in Michigan (Day *et al.* 960) and Wisconsin (Wilde 1964). For natural tands of red pine in Minnesota the growth interept method estimated site index more closely if ne measurements were made on internode engths above 8 feet rather than above breast eight (Alban 1972). An abbreviated intercept nethod (of 1 to 5 internodes) was developed to stimate site index of red pine damaged by Eurolean pine shoot moth (Schallau and Miller 1966).

In this study 165 red pine stands were used to valuate the growth intercept method for plantaons and naturally established stands, to compare esults geographically within the Lake States, and o determine the minimum age at which reliable ite index estimates can be made.

The site indices for these stands represent the entire range for red pine in the Lake States (table 1). Most stands are near or past site index age (50 years) and thus require little or no extrapolation to the 50-year site index age. Almost all stands are on deep well drained sandy soils where red pine occurs most frequently, but a few are on finer textured soils or on shallow soils underlain by bedrock. Red pine was not sampled on organic soils or poorly drained soils because of its infrequent occurrence on them. Because height growth of red pine on poorly drained sites has been shown to be abnormal (Stone *et al.* 1954), the results from this study are not applicable to these kinds of sites.

Table 1.— *Stand characteristics*

		Age		Site Index	
	Number	Mean	(Range)	Mean	(Range)
Natural Stands	86	68	(44-98)	56	(37-69)
Plantations	79	37	(26-71)	62	(38-77)

METHODS

Ninety-nine sample stands, about equally divided between plantations and natural stands, were used to develop equations relating site index to growth intercept and 66 additional stands (check stands) were used to test and verify them. About two-thirds of the stands are in Minnesota and the rest are in Wisconsin and Michigan.

In each stand data were collected on 3 to 20 dominant or codominant trees for site index (SI), growth intercept (GI), and number of years to

reach breast height (BH). Measurement trees in the sample stands were felled and total age determined by adding 2 years to the ring count at a 3- to 6-inch stump. Internode lengths were measured from the top of the tree down as far as they were visible. The bole of older trees without visible lower branches was sectioned at 1- to 2-foot intervals and ring counts made to construct a height-growth curve (Curtis 1964) from which growth intercept was estimated (Alban 1972). Measurement trees in about half of the check stands were not felled. For these trees total age was determined from increment cores, total height was measured with an abney, and internode lengths were measured with a calibrated 13-foot pole.

Site index was measured directly on most of the stands more than 50 years old by determining height at age 50 from stem analysis. For stands younger than 50 years and for older stands without stem analysis data, site index was estimated from total height and age using a site index equation (Lundgren and Dolid 1970) that was developed from site index curves (Gevorkiantz 1957). The site index equations result in good estimates of site index for this study because the stands are close to site index age (table 1) and because the height-growth of these stands was found to follow closely the red pine site index curves (Alban 1976). Site index determined by stem analysis or by site index equations is referred to as the *standard site* index and serves as the reference for comparing the various growth intercept estimates of site index. Differences between the standard site index and site index estimated from growth intercept are referred to as error. And the average error is the average difference between the standard site index and site index estimated from growth intercept for all stands.

Site index was related to growth intercept using several curve forms including linear, 2nd and 3rd order polynomial, log and log-log. The best fit was obtained using the form:

$$\text{Site Index} = b_0 + b_1 (GI) + b_2 (GI)^{-2}$$

RESULTS AND DISCUSSION

Growth Intercept Above 8 Feet

The relation between red pine site index and the total length of 5 internodes beginning at the first whorl above 8 feet (GI_8) is significant at the 0.0 probability level (fig. 1):

$$\text{Site Index} = 36.9 + 3.356\ (GI_8) - 192.474\ (GI_8)^{-2}\ (1$$

$R^2 = 0.79$, SE = 4.11 feet, n = 99

The potential site index of a red pine stand can be obtained by measuring the growth intercept o suitable trees and utilizing either equation (1) or the following:

Growth intercept (GI_8)[1] (feet)	*Site index* (feet)
4	38.3
5	46.0
6	51.7
7	56.5
8	60.7
9	64.7
10	68.5
11	72.2
12	75.8

[1] GI_8 = the total length of 5 internodes beginning at the first whorl above 8 feet.

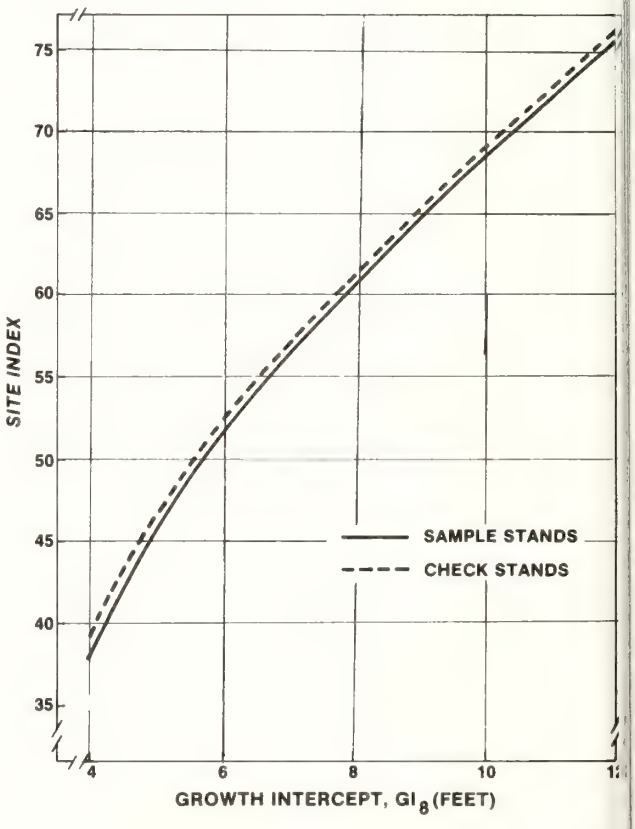

Figure 1.— *Relation between red pine site index and 5-year growth intercept beginning at the first whorl above 8 feet for sample and check stands.*

The trees used for measuring growth intercept should be dominant or codominant trees that have never been suppressed or had serious insect, disease, animal, or storm damage. They should be part of a well-stocked even-aged stand that has no evidence of major fire or other environmental disturbance of the site since stand establishment. In addition, of course, the growth intercept method requires the presence of branch whorls beginning at least as low as 8 feet.

In our experience the average growth intercept of uniform stands can be estimated within a few tenths of a foot by measuring from 10 to 20 trees scattered throughout the stand. Of course, if soils or topography vary significantly within the stand, stratification will be necessary. To estimate site index to the same level of precision more growth intercept measurements are required from the poorer sites because the curve is steeper for poor sites than for good sites (fig. 1). For example, a 1-foot error in measuring a 4-foot growth intercept would result in an error in site index estimation of nearly 8 feet whereas a 1-foot error in a 12-foot growth intercept would result in a site index error of only 4 feet.

The growth intercept is easy to measure and the method doesn't require the determination of tree age or height. Growth intercept may be useful for rapidly appraising the site index for older stands, but its most important application will be in young stands.

Generally, red pine stands more than 16 years old will be tall enough to measure growth intercept. Up to an age of 25 years the growth intercept method will give a more accurate estimate of site index than measurement of total height and age and use of site index curves (Alban 1972). This is so primarily because with growth intercept one avoids the erratic early height growth that is often related to factors other than site. From ages 25 to 30 these two methods of site index estimation work about equally well, but beyond about 30 years site index curves will usually give the best measure of site index and should be used where precise determinations are desired.

Testing of Results

The reliability of the growth intercept method was evaluated on 66 check stands. The check stands are about equally divided between plantations and natural stands, and about half are in Minnesota and half are in Wisconsin and Michigan. The check stands represent approximately the same range and average SI values as the sample stands. The equation developed from the sample stands (equation 1) estimated site index of both sample and check stands with the same average error (table 2). And the percent of stands with site index errors less than 5 or 10 feet was nearly identical for sample and check stands. About 80 percent of the site index estimates are within 5 feet of the actual site index.

An equation was developed to estimate site index from the growth intercept of the 66 check stands. The coefficients of this equation did not differ significantly (0.05 level) from those developed from the sample stands, and the R^2 value (0.80) and SE (4.23) were nearly identical to those of the sample stands. Site index estimates from this equation differed by less than 1 foot from those developed from the sample stands (fig. 1). Because the sample stands and the check stands obviously represent the same population, their data were combined to make a larger sample size for statistical testing.

Natural Stands vs. Plantations

To directly compare the relation between site index and GI_8 for plantations and natural stands, separate equations were developed for all of the natural stands (both sample and check stands, n=86) and similarly for all plantations (n=79) (fig. 2). Up to a growth intercept of 10 feet the natural stands and plantations differ little in predicted site index and both are close to the SI estimated from the sample stands. At a GI_8 of 10 feet the estimated site indices of plantations and natural stands begin to diverge and by a GI_8 of 12 feet they differ by about 3 feet.

However, we found no natural stands with a GI_8 greater than 10 feet, and the site index for the plantations at a GI_8 of 12 feet differs by only about 1 foot from that estimated from the sample stands. Thus, equation (1) should be applicable to both plantations and natural stands within the common range of GI_8 values. This is verified by the similar precision with which equation (1) predicts site index for plantations and natural stands

Table 2.— *Reliability of the GI_8 method when applied to check stands, sample stands, plantations, natural sta[nds] and to different geographical areas*

Stands	Average site index	Average error in estimated site index	Stands with site index estimated within		
			±2.5 feet	±5 feet	±10
	Feet		*Percent*		
Sample	58	3.3	45	79	100
Check	59	3.3	39	80	98
Natural	56	3.1	47	85	99
Plantation	62	3.4	39	77	100
Minnesota	58	3.2	44	83	99
L. Michigan	57	3.4	42	71	100
Wisconsin + U. Michigan	60	3.3	39	82	100

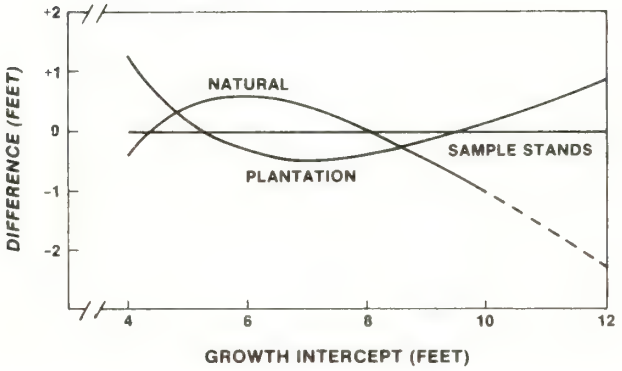

Figure 2.— *Difference of site index predicted from equations developed for plantations or natural stands from those developed for sample stands.*

(table 2). For both kinds of stands the average error in estimating site index is about 3 feet. Site index was estimated within 5 feet for about 80 percent of all stands and only one natural stand had a site index error greater than 10 feet.

Geographical Effects

Stands from Minnesota, Lower Michigan, and Wisconsin plus Upper Michigan all have site index reliably estimated from equation (1). The average error in estimated site index ranged from 3.2 feet for Minnesota to 3.4 feet for Lower Michigan (table 2).

A SI—GI_8 relation developed from all of the Minnesota stands (n=113) was compared with one developed from all of the stands from Michigan plus Wisconsin (n=52) and with all stands from Lowe[r] Michigan (n=24). Solving the equations for sit[e] index and comparing the results with site inde[x] estimates from the sample stands (equation 1[)] shows little difference (fig. 3). Site indices esti[-] mated from the Minnesota stands differ from thos[e] estimated from the Upper Michigan and Wiscon[-] sin stands by less than 2 feet, and neither of thes[e] differs from those estimated from the sampl[e] stands by much more than 1 foot. Larger differ[-] ences occurred for the Lower Michigan stands bu[t] even here the differences were less than 3 fee[t] within the common range of GI_8 values.

Thus, based on direct site index comparison[s] (table 2) and on equations developed from each area (fig. 3), there is no significant geographical

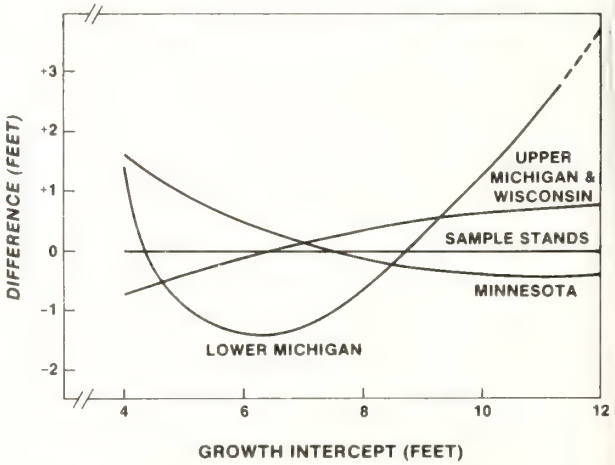

Figure 3.— *Difference of site index predicted from equations developed for stands from Minnesota, Wisconsin, and Michigan from those developed for sample stands.*

difference in the SI-GI_8 relation. Consequently, equation (1) is applicable to red pine stands throughout the Lake States and may be applicable to red pine throughout its natural range (Alban 1972).

Growth Intercept BH or 8 Feet?

All stands that had measurements of growth intercept above breast height and 8 feet (n=152) were used to compare these two starting heights for growth intercept. Equations of the form $SI=b_o+b_1\ (GI)+b_2\ (GI)^{-2}$ were developed for growth intercepts above BH and 8 feet. In addition the site index of each stand was estimated from the growth intercept equation of Day *et al.* 1960 [Site Index= $-0.0002+12.529\ (GI_{BH})-0.5166\ (GI_{BH})^2$]. The actual site index of each stand was compared with site index estimated by each of these three methods (table 3).

The growth intercept above 8 feet is clearly superior to that above breast height for estimating site index. The average site index error was 3.3 feet for the GI_8 method compared to 4.9 and 5.2 feet for the GI_{BH} methods. When the GI_8 method was used, less than 1 percent of the site index estimates were off by more than 10 feet. However, when the GI_{BH} methods were used, 9 and 14 percent of the stands had errors more than 10 feet and a few plots had errors larger than 15 feet.

It is not surprising that a growth intercept measured higher up the tree is a better estimater of site index than one measured lower because early red pine height growth is not well correlated with later height growth. For example the years required for red pine to reach breast height is not closely related to either site index or growth intercept (Alban 1972, Day *et al.* 1960, Ferree *et al.* 1958). Climate, stock quality, planting techniques, brush competition, and animal damage all affect early height growth more than later growth. These early effects may influence growth after the trees attain breast height but become much less pronounced after the trees reach 8 feet (Alban 1972).

Use With Younger Stands

GI_{BH} is a less reliable estimator of site index than GI_8, but it can be used at an earlier age. In the current study, GI_{BH} could be used to estimate site index at an average stand age of 13 years while GI_8 could not be used until a stand reached an age of 16.

To examine the possibility of lowering the age at which growth intercept could be used to estimate site index, height growth for from 1 to 4 years above 8 feet was correlated with site index for all

Table 3.— *Comparison of growth intercept methods*

Growth intercept[1]	Stands	Average error in estimated site index	Stands with site index estimated within ±5 feet	±10 feet	±15 feet	Regression equations R^2	$S\bar{x}$
	No.	*Feet*	*Percent*				
$GI_{8/5}$	[3]152	3.3	79	99	100	0.78	4.2
$GI_{BH/5}$	152	4.9	57	91	99	.54	6.1
[2]$GI_{BH/5}$	152	5.2	57	86	99	.84	5.7
$GI_{8/4}$	[3]96	3.9	76	94	100	.75	5.0
$GI_{8/3}$	96	4.1	65	94	100	.72	5.3
$GI_{8/2}$	96	5.1	52	90	100	.58	6.4
$GI_{8/1}$	96	5.9	49	82	99	.45	7.4
$GI_{BH/5}$	96	5.0	59	89	99	.60	6.4
$GI_{BH/3}$	96	5.8	48	82	96	.46	7.4

[1]The symbol preceding the slash is the height above which GI is measured, and the number after the slash is the number of internodes included in the GI measurement.
[2]Equation of Day *et al.* (1960) applied to stands of the current study.
[3]The total number of stands in this study is 165. However, GI_{BH} and individual internode lengths were not measured for all stands.

stands that had clearly visible whorls down to breast height (n=96) (table 3). These stands were about equally divided between natural stands and plantations, and their mean and range of values for site index and GI_8 were nearly identical to those of the sample stands.

We found that the precision of estimating site index increased as the number of internodes above 8 feet used for the estimation increased (table 3). Using only one internode resulted in large errors due probably to year-to-year climatic variations. The differences in the precision of site index estimation from 3 to 5 internodes was not large, but the use of 5 internodes was the most accurate. Of interest is the fact that using only 2 internodes above 8 feet predicts site index to almost the same level of precision as using the full 5 years above breast height (table 3).

The first 2 internodes above 8 feet are generally the last 2 internodes of the GI_{BH} growth intercept. The fact that the last 2 internodes are able to predict site index as accurately as the full 5 above BH indicates the limited usefulness of the first few internodes above breast height. In the current study the first 3 years' height growth above breast height were related to site index by an R^2 of only 0.46, with a standard error of 7.4 feet (table 3). Growth intercept for 3 years above BH resulted in large errors in estimated site index for many stands, and both the average error and the distribution of errors are similar to those obtained using only the first internode above 8 feet (table 3). Clearly the first few internodes above breast height are of limited usefulness in estimating site index.

Our data indicate that the youngest age at which a reliable estimate of site index can be made is about 2 years after the trees reach 8 feet, which is usually when the trees are about 13 years old. Attempts to determine site index from height growth at younger ages may result in large errors and the forester is best advised to either find other methods of estimating site potential (adjacent stands, understory, soil) or to delay until the stands are older.

Once the stand has grown for at least 2 years past the 8-foot height, reasonable site estimates can be made using the average internode length for 2 to 4 internodes above 8 feet from the following tabulation:

Average annual height growth (feet)	Site index (feet)
0.8	40
1.0	47
1.2	52
1.4	57
1.6	61
1.8	65
2.0	69
2.2	73
2.4	77

The larger the number of internodes included in the measurement, the more accurate will be the estimate and for best results, the full 5-year growth intercept above 8 feet should be used.

Polymorphic Height Growth

Site index determined by either the growth intercept method or by site index curves will be in error if the site's early height growth pattern is different from that of the sites used to develop the site index curves or the SI-GI relation. (Carmean 1975, Wilde 1964). In the current study a few stands had abnormal height growth patterns. We found normal early growth followed by growth declines on shallow soils over bedrock and on sandy soils underlain by infertile beach sands, and we found slow early growth followed by growth increases on soils with deep fertile layers. But these deviations were the exception and the vast majority of sites closely followed the height growth patterns expected from the site index curves (Gevorkiantz 1957).

SUMMARY AND CONCLUSION

We developed equations—based on the close relation between the total length of the first 5 internodes beginning at the first whorl above 8 feet (growth intercept) and site index—that accurately predict site index for young red pine stands. This growth intercept method can be applied in stands as young as about 16 years and with some loss in precision even in stands as young as 13 years. Up to a stand age of 25 or 30 years, the growth intercept method will estimate site index better than

conventional site index curves. The equations are applicable to red pine stands throughout the Lake States and to natural stands as well as plantations.

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Red pine stands throughout the Lake States were sampled to determine the relation between site index and bole internode lengths. The total length of 5 internodes beginning at the first whorl above 8 feet is a good estimater of site index (average error 3.3 feet) for both plantations and natural stands throughout the Lake States.

OXFORD: 541:561.1:174.7 (Pinus resinosa):(77). KEY WORDS: Growth intercept, internode length, site index, stem analysis.

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A comparison of site index curves for northern hardwood species

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A COMPARISON OF SITE INDEX CURVES FOR NORTHERN HARDWOOD SPECIES

Willard H. Carmean, *Principal Soil Scientist*

Northern hardwoods are among the more important and widespread forest types found in the eastern hardwood forests of the United States and Canada. In the United States, forest types composed primarily of northern hardwood species cover about 37 million acres in the Northeast, the Lake States, and the Appalachian Plateau (U.S. Department of Agriculture, Forest Service 1973). Characteristic species are sugar maple (*Acer saccharum* Marsh.), red maple (*A. rubrum* L.), yellow birch (*Betula alleghaniensis* Britton), and American beech (*Fagus grandifolia* Ehrh.). In certain areas, American basswood (*Tilia americana* L.), American elm (*Ulmus americana* L.), and white ash (*Fraxinus americana* L.) are important stand components. Other associated species of less frequent occurrence include black ash (*F. nigra* Marsh.), black cherry (*Prunus serotina* Ehrh.), northern red oak (*Quercus rubra* L.), paper birch (*B. papyrifera* Marsh.), and both quaking (*Populus remuloides* Michx.), and bigtooth aspens (*P. grandidentata* Michx.).[1]

Northern hardwood stands not only have a large number of tree species, but throughout their wide range also occur in a great variety of climates, and grow on a great variety of topographic positions and soils. Site quality and growth rate may vary greatly for each species of tree when growing on these different sites. Faced with such a profusion of tree species and site conditions, a forest manager is often uncertain about how best to estimate site quality in northern hardwood stands.

Site index based on tree height growth is the most widely accepted method for estimating site quality in the United States and Canada (Carmean 1975, 1977). The method is simple and easy to use when suitable forest trees are available for the required height and age measurements. Such trees are most commonly found in even-aged, fully stocked stands not disturbed by past cuttings, severe fires, or heavy grazing. Even-aged, fully stocked stands are common throughout the range of northern hardwood species. They developed following the removal of the original old growth hardwood stands by clearcutting or heavy harvest cutting. Dominant and codominant trees in these young, even-aged northern hardwood stands are well suited for site index estimation, just as the dominant and codominant trees found in even-aged conifer stands are.

Many site index curves are available for use in the various portions of the large area covered by northern hardwood species. However, many of these are older harmonized site curves based only on tree height-age measurements rather than on more precise stem analysis methods. Also many site index curves are only local curves based on a limited range of soil and site conditions. Within the large area covered by northern hardwood species, a forester may find several sets of site index curves, but he may be uncertain about how applicable they may be to the specific site conditions of his local area.

Intensive timber management requires more precise site index estimates than are usually possible using the older, general, harmonized site index curves. We need to critically examine existing site index curves for northern hardwoods to determine if they are accurate and adequate for use in the precise estimation of site index. We need to know what set of site curves are most suitable for local use. If local site index curves are lacking, inaccurate, or too general, we should try to obtain site index curves that are suitable for the forest and site conditions of that area.

[1] *Tree names follow Little (1953).*

I have three goals for this paper: (1) to inventory the many site index curves presently available for northern hardwood species (table 1); (2) to compare the predicted height growth patterns of these many site index curves (figs. 1-3); and, (3) to recommend additional more accurate site index curves suitable for intensive timber management of the future.

Table 1. Inventory of site index curves for northern hardwood forest species.

Species	Area	Study Methods	Reference
Sugar maple, yellow birch, American beech, white ash	Vermont	Single height-age curves	Hawes and Chandler (1914)
Sugar maple, yellow birch, American beech, American basswood	N. Wisconsin and N. Lower Michigan	Single height-age curves	Frothingham (1915)
Sugar maple, white ash	Vermont	Harmonized	Farrington and Howard (1958)
Red maple, American beech, black cherry	NE States	Site Index curve summary	Hampf (1965)
Sugar maple	S. New York	Stem analyses	Farnsworth and Leaf (1963)
Sugar maple, yellow birch, white ash, paper birch	Green Mts. of Vermont	Stem analyses	Curtis and Post (1962)
Sugar maple	N. Lower Michigan	Stem analyses	Shetron (1972)
Sugar maple, red maple, yellow birch, American beech, American elm, American basswood, white ash, black ash, black cherry, northern red oak, paper birch, aspens	N. Wisconsin, Upper Michigan	Stem analyses	Carmean (1978)
Black cherry	NW Pennsylvania	Stem analyses	Ward *et al.* (1965)
American elm	SE and W Iowa	Harmonized	Brendemuehl *et al.* (1961)
Red oak	Lake States	Harmonized	Gevorkiantz (1957)
Paper birch	N. Wisconsin	Harmonized	Cooley (1958)
Quaking aspen, paper birch	Ontario	Stem analyses	Plonski (1956)
Quaking aspen, paper birch	Alaska	Stem analyses	Gregory and Haack (1965)
Quaking aspen	Lake States	Harmonized	Gevorkiantz (1956)
Quaking aspen, bigtooth aspen	N. Lower Michigan	Harmonized	Graham *et al.* (1963)
Quaking aspen	N. Cent. Minnesota	Growth plot remeasurements	Schlaegel (1971)
Quaking aspen	Saskatchewan	Harmonized	Kirby *et al.* (1957)
Quaking aspen	Cent. and S. Rocky Mts.	Stem analyses	Jones (1966, 1967)
Quaking aspen	Newfoundland	Harmonized	Page (1972)

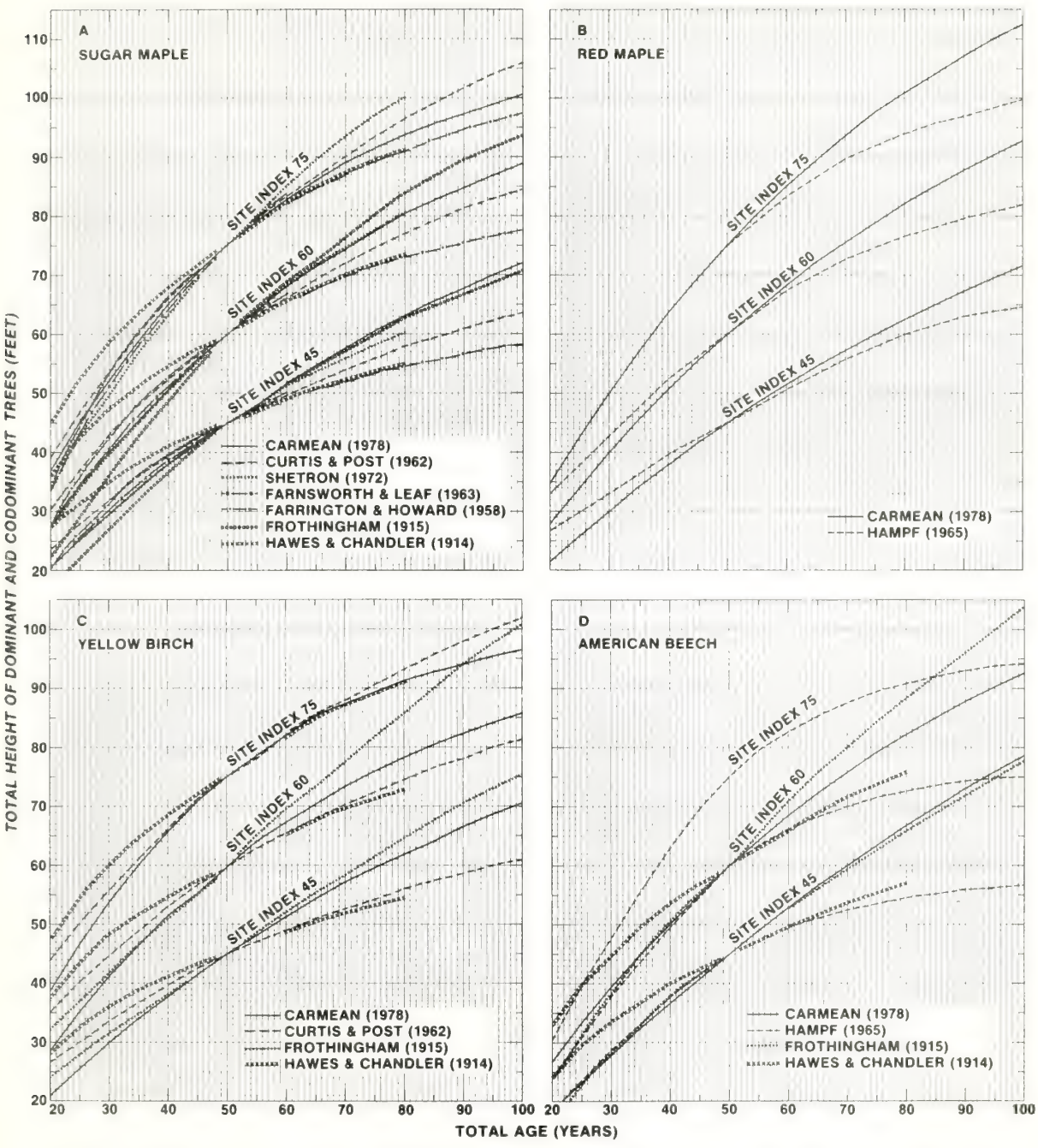

Figure 1.—*Site index curve comparisons at the poor (SI 45), medium (SI 60), and good (SI 75) site index levels for sugar maple, red maple, yellow birch, and American beech.*

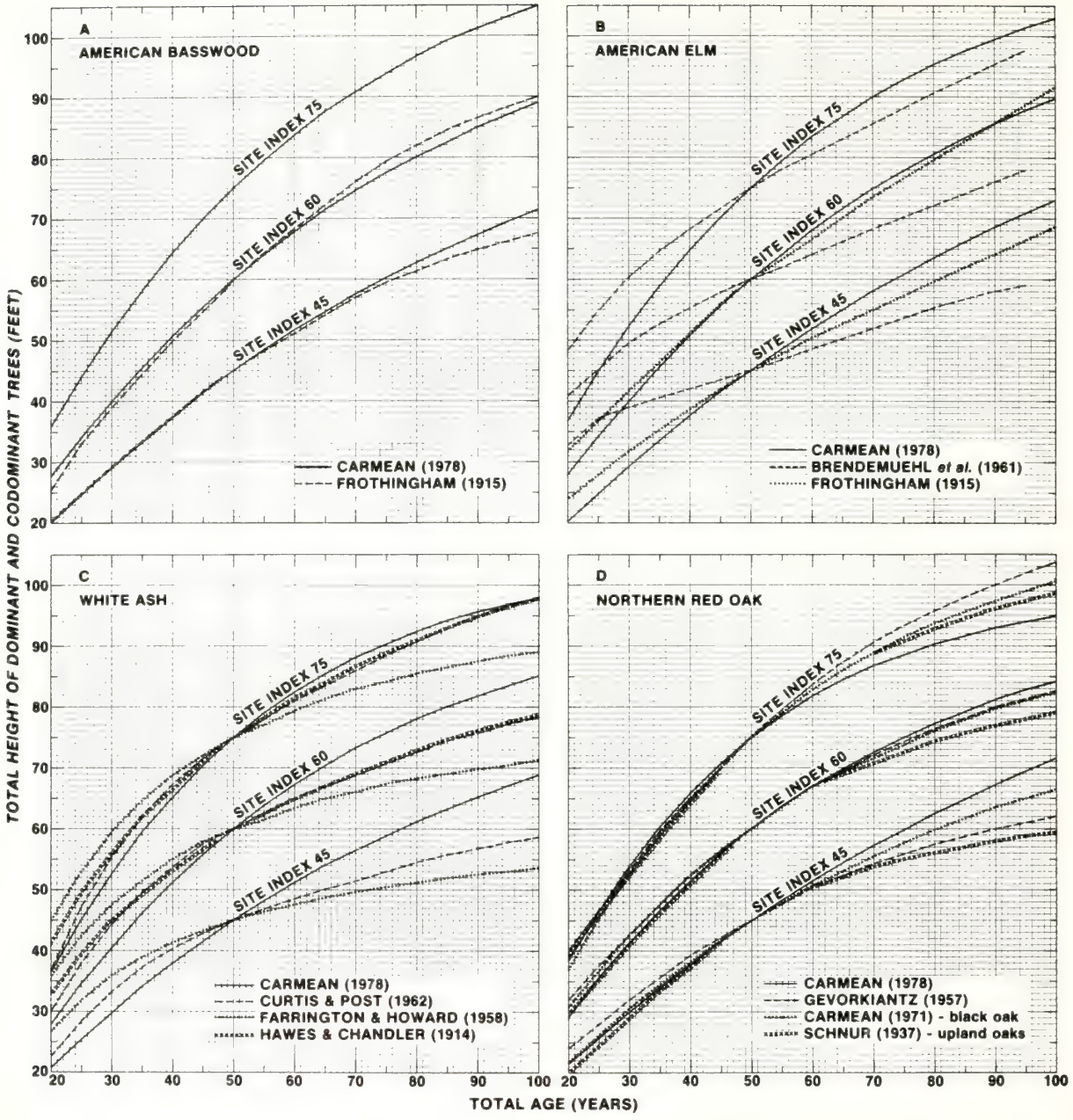

Figure 2.—*Site index curve comparisons at the poor (SI 45), medium (SI 60), and good (SI 75) site index levels for American basswood, American elm, white ash, and northern red oak.*

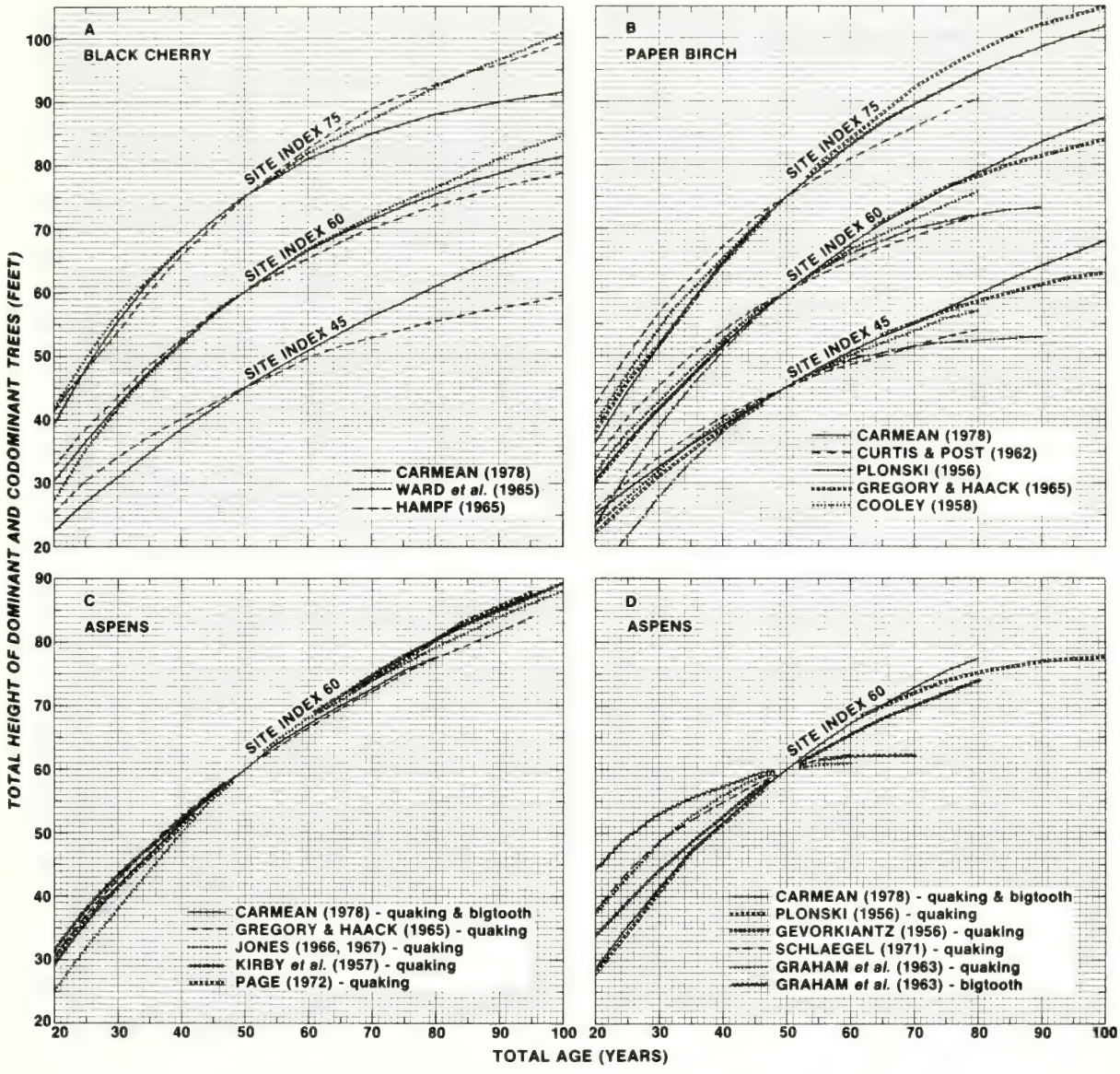

Figure 3.—*Site index curve comparisons at the poor (SI 45), medium (SI 60), and good (SI 75) site index levels for black cherry and paper birch. Site index curves also are compared at the medium (SI 60) site index level for bigtooth and quaking aspens.*

INVENTORY AND COMPARISON OF SITE INDEX CURVES FOR NORTHERN HARDWOOD SPECIES

The inventory revealed that many site index curves have been published for different portions of the large area covered by northern hardwood species (table 1). Also, many of these site index curves have been formulated so that rapid computer computations of site index can replace the slow and tedious interpolations required using site index graphs (Lundgren and Dolid 1970; Payandeh 1974a, 1974b, 1977; Monserud and Ek 1976).

New site index curves are now available for use in northern hardwood stands of northern Wisconsin and Upper Michigan (Carmean 1978). These new curves are based on stem analyses of 3,402 trees growing in even-aged stands on soils having a wide range of site index. Separate site index curves are given for 13 species, including curves combining data for quaking and bigtooth aspens, and the first site curves published for black ash.

Most of the new site curves have pronounced polymorphic height growth patterns. These results agree with previous studies that show many tree species have different height growth patterns for different levels of site quality, or in different parts of their range (Carmean 1970, 1975). The new site curves usually have similar height growth patterns before age 50, even though species such as American basswood, American elm, and the ashes grow more rapidly before that age. However, after age 50, pronounced differences in patterns of height growth usually are evident for species growing on medium and good sites.[2] These later differences in height growth are so great that accurate site index estimation requires separate sets of curves for each species.

The new site index curves for northern Wisconsin and Upper Michigan and the previous site curves were compared at the poor (SI 45), medium (SI 60), and good (SI 75) levels of site index (figs. 1-3). Comparisons also were made at the medium (SI 60) level of site index for quaking and bigtooth aspens (fig. 3C and 3D). Most of the previous site index curves used 50 years as the index age, and most are based on total tree age. However, a few curves used younger (Graham *et al.* 1963), or older (Curtis and Post 1962, Jones 1966, 1967) index ages. Some curves used breast height age instead of total age (Curtis and Post 1962, Jones 1966, 1967, Page 1972, Shetron 1972). Also, some studies do not give site index curves, but only single average height-age curves (Hawes and Chandler 1914, Frothingham 1915, Plonski 1956, Kirby *et al.* 1957, Farnsworth and Leaf 1963, Ward *et al* 1965). These exceptions were considered and appropriate adjustments were made so that all site index curves could be compared using total tree age, and 50 years as the site index reference age.

[2]*Carmean, Willard H. Site index curves for northern hardwoods in the Lake States. (Unpublished manuscript on file at the North Central Forest Experiment Station, St. Paul, Minnesota.)*

Sugar Maple

Height growth for sugar maple (fig. 1A) has been studied more than for other northern hardwood species. However, three of the seven sugar maple curves (Hawes and Chandler, Frothingham, and Farrington and Howard) are harmonized curves based only on total height and age measurements, and are less accurate than the four curves based on stem analyses. Observe how the Hawes and Chandler, and the Farrington and Howard, curves show a much slower pattern of later height growth than the other curves. In contrast, for medium sites (SI 60) Frothingham's curve shows much more rapid height growth in later years than the other curves; for poor sites (SI 45) and older ages his curve agrees closely with mine.

The Farnsworth and Leaf stem analysis curves for southern New York only extend to about 60 years. Height growth during this period closely parallels the growth pattern of my curves and the Shetron curves for the Lake States. No information is available about height growth patterns after age 60 for sugar maple in New York.

The two curves for the Lake States (Carmean, Shetron) agree closely for medium sites (SI 60), but not for good (SI 75) and poor (SI 45) levels of site index. For good sites my curves show slower later height growth, and for poor sites my curves show faster, later height growth than predicted by Shetron's curves. Before 50 years our curves predict similar height growth, except for good sites where Shetron's curves predict somewhat slower growth than mine.

The differences between Shetron's curves and mine probably are due to his limited amount of data, and to differences in methods of computation. Shetron's curves are based on 15 plots with 25 trees ranging from about site index 43 to 64, while my curves are based on 177 plots with 721 trees ranging from site index 42 to 75. This larger data base over a wider range of site index enables me to better define the polymorphism associated with different levels of site. Furthermore, the nonlinear regression models I used allowed for full expression of polymorphism, whereas the simple quadratic regression model used by Shetron is not suited for expressing polymorhpic height growth.

The close fit between the two Lake States curves at the medium (SI 60) site index level indicates that height growth patterns in my study area are similar to growth patterns in northern lower Michigan. This is to be expected because the two areas have similar climate, soil, and topography. However, the more these conditions differ from my study area, the more caution should be exercised in applying my site curves to other areas.

The Curtis and Post site index curves for the Green Mountains of Vermont differ markedly from the height growth patterns for sugar maple in the Lake States. For both medium (SI 60) and poor (SI 45) sites, their curves predict much slower growth after 50 years than mine; for good sites (SI 75), their curves predict more rapid later growth than mine. For all levels of site index, the Curtis and Post curves predict more rapid growth before 50 years than predicted by the two Lake States curves. Apparently sugar maple in the White Mountains of New Hampshire also has a height growth pattern similar to sugar maple in the Green Mountains of Vermont because Solomon (1968) found that the Curtis and Post site index curves for sugar maple, yellow birch, white ash, and paper birch were applicable in New Hampshire.

These comparisons indicate that sugar maple in Vermont and New Hampshire may have more rapid early height growth, and slower later height growth than sugar maple in northern Wisconsin and Upper Michigan. But additional studies are needed to determine if this same height growth pattern occurs in other New England and Middle Atlantic States where climate, soil, and topography are different from the mountains of Vermont and New Hampshire. Studies also are needed in eastern Canada and in the Appalachian Mountain region to determine height growth patterns and the possible need for separate site index curves.

The polymorphic nature of my site curves is the major reason why they do not agree in later years with the Curtis and Post curves, or with the Shetron curves. Both of the latter curves have an anamorphic pattern of height growth, i.e., the curves have the same shape at all levels of site index. In contrast, my polymorphic curves have different shapes for different levels of site index. As a result, even though my curves agree with Shetron's curves for medium sites, the agreement for other sites is poor due to this polymorphism. Such results emphasize the need to compare site index curves for all sites, not just medium sites. These results also show the need for height growth data at all levels of site index and the need for equation models that will adequately express polymorphic height growth.

Red Maple

Height growth data for red maple (fig. 1B) is limited, and the only previous site curves are those of Hampf. Hampf's curves are based on stem analysis data reported by Foster (1959) for 71 trees located in old fields of northern Connecticut, western Massachusetts, and eastern New York; Hampf extrapolated these curves to 100 years even though Foster's average height-age curve extended only to 60 years. Solomon (1968), using stem analyses for 18 red maples in New Hampshire, concluded that Hampf's site curves could be used with acceptable accuracy for trees older than 40 years. But adjustments were suggested for younger ages because the Hampf curves apparently predicted more rapid early height growth than Solomon observed for red maple in New Hampshire.

Comparisons between my curves and the Hampf curves indicate that both red maple and sugar maple in the northeast may grow more rapidly in early years and more slowly in later years than do maples in the Lake States. My red maple curves predict exceptionally rapid later height growth on good sites, but the accuracy of Hampf's projected pattern of later height growth is questionable because Foster's original data extended only to 60 years.

My red maple curves probably are applicable to northern lower Michigan where climate, soil, and topography are similar to conditions in my study

area. However, red maple has a very wide range so more studies in other areas are needed before my curves can be applied with confidence elsewhere. Special efforts should be made to accurately determine the pattern of later height growth on good sites.

Yellow Birch

Four curves were found for yellow birch (fig. 1C), but two of these (Hawes and Chandler, Frothingham) are single average curves that are based only on measurements of total height and age. The Hawes and Chandler curve predicts exceptionally rapid early height growth, and exceptionally slow later height growth. In contrast, the Frothingham curves predict exceptionally rapid later height growth.

The Curtis and Post curves for Vermont, which also are applicable in New Hampshire (Solomon 1968), differ markedly from the height growth patterns for yellow birch and other species in the Lake States. As for sugar and red maple, the Curtis and Post curves predict faster early height growth than do mine. After 50 years, their curves predict slower growth than mine on medium (SI 60) and poor (SI 45) sites; for good sites (SI 75) their curves predict faster later height growth than mine.

As discussed earlier, many of the curve differences on good and poor sites are due to the polymorphic nature of my curves in contrast to the anamorphic nature of the Curtis and Post curves. My yellow birch curves have a particularly strong polymorphic growth pattern resulting in a pronounced slowing in later height growth for trees on good sites, in contrast to the more linear and sustained later height growth for trees on poor sites.

American Beech

Only four site curves were found for American Beech (fig. 1D); of these, only my curves are based on stem analyses. My curve for poor sites (SI 45) is similar to Frothingham's height-age curve, but his curve for medium sites (SI 60) predicts more rapid later height growth than mine. The Hawes and Chandler curves predict unusually rapid early height growth; after 50 years their curves and the Hampf curves predict very slow height growth.

I found that even though beech has a slow early height growth, this growth is sustained in later years resulting in a more linear height growth pattern than for other hardwood species. This slow early height growth for beech produces site indices averaging about 5 to 15 feet shorter than for other species (Carmean 1979). As a result rarely do we find beech having high site indices. The highest beech site index observed in my study was 61 feet. Frothingham, and Hawes and Chandler only give curves for medium and poor sites; they also apparently found few high site indices for beech. Only Hampf gives a curve for good (SI 75) beech sites, but his curve may be an extrapolation beyond observed site conditions.

American Basswood

The only previous site curves for basswood (fig. 2A) are based on average height-age data from northern Wisconsin and northern Michigan. These curves predict early height growth similar to mine, but after 50 years the Frothingham curves predict somewhat faster height growth on medium sites (SI 60), and somewhat slower growth on poor sites (SI 45). Frothingham apparently has few observations for good sites judging from the rather slow growth shown by his average height-age curve.

American Elm

Frothingham's curves (fig. 2B) are based on a single average height-age curve. The Brendemuehl *et al.* harmonized site curves for Iowa are based on total height and age values; they also included some measurements of slippery elm (*U. rubra* Muhl.). My curves appear similar to Frothingham's Lake States curve at the medium (SI 60) site index level, but at the poor (SI 45) site index level his curve predicts slower later growth than mine. The Brendemuehl *et al.* curves shows exceptionally rapid early height growth, and exceptionally slow later growth for all sites. Possibly part of the reason for these differences is that my study area has climate and soil very different from the bottomland soils studied in Iowa. These climate and soil differences may result in a different rate of early height growth, and also in different patterns of tree height growth.

White Ash

The Hawes and Chandler curve (fig. 2C), and the Farrington and Howard harmonized site index curves, are based only on total height and age measurements; the Curtis and Post curves and my

urves are based on stem analyses. The Farrington nd Howard curves predict unusually rapid early eight growth, and unusually slow later height rowth for all sites. In contrast, the two Vermont urves (Hawes and Chandler, Curtis and Post) are imilar for medium (SI 60) and good (SI 75) sites. Ay curves predict slower height growth before 50 ears, and more rapid later height growth than do ny of the other three white ash curves. After 50 ears on good sites, my curve is fairly similar to he growth predicted by the Curtis and Post urves. However, for medium sites the Curtis and ost curves predict considerably slower later rowth than my curves; for poor sites these differnces are even more pronounced.

Northern Red Oak

The only previous curves for northern red oak ig. 2D) are the harmonized site index curves of evorkiantz. At the medium (SI 60) site level his ed oak curves agree fairly well with my red oak urves, and, with my stem analysis curves for lack oak (*Q. velutina* Lam.) in the Central States. ut the older generalized site index curves for all pecies of oak (Schnur 1937) predict slower later rowth for both medium (SI 60) and poor (SI 45) ites than do the other three curves.

The close agreement for medium sites observed etween Gevorkiantz's curve and my red oak and lack oak curves does not occur for good (SI 75) or oor (SI 45) sites. For good sites my red oak curve redicts slower height growth after 50 years; and or poor sites more rapid later height growth. The eason for these differences at good and poor site evels is that my red oak curves have pronounced olymorphism, my black oak curves have less olymorphism, and the Gevorkiantz curves have nly a single anamorphic pattern of height rowth.

Black Cherry

My curves agree fairly well with the Ward *et al.* tem analysis curves (fig. 3A), and with the Hampf armonized curves at the medium (SI 60) level of ite index. But for poor sites (SI 45) Hampf's curves redict much slower later height growth than ine, and for good sites (SI 75) both the Hampf and he Ward *et al.* curves predict much more rapid ater height growth than predicted by my curves. ata from the Northeast and the Appalachians re limited, thus additional height growth studies re needed for this prized tree.

Paper Birch

Cooley's curves are based on total height-age data and on harmonizing methods, and the other four curves are based on stem analyses (fig. 3B). Comparisons at the medium (SI 60) and poor (SI 45) site index levels show that the previous curves predict slower later height growth than mine; the Plonski curves, and the Curtis and Post curves predict particularly slow later height growth at all levels of site index. In contrast, comparisons at the good (SI 75) site index level show very close agreement between my curve and the Cooley curve; the Gregory and Haack curve for Alaska predicts later height growth that is somewhat more rapid than predicted by mine.

Paper birch has a very wide geographical range covering diverse climatic, topographic, soil, and site conditions. Throughout this wide range site, quality differs greatly as do patterns of height growth (fig. 3B). I recommend many additional stem analyses leading to the construction of polymorphic site index curves for paper birch.

Aspens

My data are limited so all quaking and bigtooth aspen stem analysis data were combined and a single set of aspen site index curves were computed. Because data were limited, polymorphic height growth for aspen was not expressed as well as for other hardwood species, so comparisons (figs. 3C and 3D) are made only for the medium (SI 60) sites.

A greater number of site index curves are available for quaking aspen than for the other northern hardwood species. Of the 9 curves, 4 are harmonized curves (Gevorkiantz, Graham *et al.*, Kirby *et al.*, Page); Schlaegel's curves are based on repeated height measurements from permanent growth plots; the remaining 4 curves are based on stem analyses (Plonski, Gregory and Haack, Jones, Carmean).

My curves combining quaking and bigtooth aspen data agree well with the Gregory and Haack quaking aspen curve for Alaska. Jones' curve for the Rocky Mountains, the Kirby *et al.* curve for Saskatchewan, and the Page curve for Newfoundland, all predict more rapid later growth than mine (fig. 3C). Aspen in the Rocky Mountains is known to be longer-lived than in the Lake States, thus perhaps explaining this more sustained later height growth. In contrast, Plonski's curve for Ontario, and Gevorkiantz's curve for the Lake States,

predict slower later height growth than mine (fig. 3D).

Growth prior to 50 years is similar for most quaking aspen site curves. An exception is Jones' curve for the Rocky Mountains that predicts slower earlier height growth than all the other curves; more rapid early height growth also is predicted by the Gevorkiantz, the Schlaegel, and the Graham *et al.* curves.

The Graham *et al.* curves for both quaking and bigtooth aspen, and the Schlaegel quaking aspen curves, have a height growth pattern unlike the other site curves (fig. 3D). A possible explanation for the abrupt slowing shown by the Graham *et al.* curves is that only 11 of their quaking aspen trees were older than 50 years, and 10 of these trees were on poor sites; for bigtooth aspen only 6 trees were older than 60 years, and 5 of these were on poor sites. This abnormal concentration of older trees on poor sites is a common reason for the unrealistic downwarping in later years often shown by harmonized site index curves. The abrupt slowing shown by the Schlaegel quaking aspen curve might be due to few observations for older trees. His curves are based on 34 permanent sample plots from a small geographic area of north central Minnesota that has a limited range of soil conditions and site quality.

Quaking aspen has an extremely wide range that includes a vast variety of climates, topography, soil, and site conditions. These variable conditions probably account for much of the differences between shapes of site index curves illustrated in figures 3C and 3D. Clonal variation in both quaking aspen (Jones and Trujillo 1975) and bigtooth aspen (Zahner and Crawford 1965) also cause large differences in height growth. Other reasons for different patterns of height growth might be related to growth of aspen in pure stands in contrast to growth in mixed stands of other species such as were involved in my studies.

DISCUSSION AND RECOMMENDATIONS

1. Many site index curves are available for northern hardwood species. However, most of the early site curves are harmonized curves not based on stem analysis methods, and these curves are not usually precise enough for modern, intensive forest management. Harmonized site index curves should be considered questionable until we determine how well their predicted height growth agrees with actual growth observed for local climatic, soil and site conditions. If site index curves are lacking, or if existing curves are inaccurate or are not representative, new site index curves should be constructed that will accurately describe tree height growth for local areas where northern hardwoods occur.

2. Comparisons of the many northern hardwoods site index curves reveal pronounced differences in predicted patterns of height growth. These differences can occur at all ages and at all levels of site quality, thus illustrating that site index curve comparisons should be made for all sites rather than only for medium sites.

Some of the differences are due to limited data from limited conditions of soil and site quality. Field measurements and computation methods often are inadequate for expressing polymorphic patterns of height growth. Also, many of the differences between curves may be due to actual differences in height growth for areas contrasting in climate, topography, soil, and site quality. Such major differences in patterns of height growth need to be better defined because they are important in accurately estimating site quality, future yields, rotation lengths, and intensity of timber management.

3. Future site index curves for northern hardwoods, as well as for other tree species, should be based on stem analysis methods, internode measurements, or on observations from permanent growth plots. Data for these studies should fully represent the conditions of climate, soil, topography and site quality of the study area. Standardized methods of data collection are needed and computation methods should be used that permit an adequate expression of polymorphic patterns of height growth.

SUMMARY

The present paper inventories the site index curves for 13 northern hardwood species including sugar maple, red maple, yellow birch, American beech, American basswood, American elm, white ash, black ash, northern red oak, black cherry, paper birch, quaking aspen, and bigtooth aspen. Graphical comparisons of these site index curves at the good, medium, and poor levels of site index illustrate the variability of height growth in various portions of the range of most of these species. These comparisons also are used for discussion and recommendations about the suitability of existing curves, and the need for more precise site index curves that are applicable to local soil and site conditions.

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NUTRIENT CONTENT OF SOME TALL SHRUBS FROM NORTHEASTERN MINNESOTA

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NUTRIENT CONTENT OF SOME TALL SHRUBS FROM NORTHEASTERN MINNESOTA

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As part of studies of tall shrubs from northeastern Minnesota (Ohmann *et al.* 1978, Grigal *et al.* 1976, Grigal and Moody[1]), we obtained data on the nutritive value of shrubs for herbivores. In one study we collected samples of the following tall shrubs at 2-week intervals from June 15 through December 8 in the Superior National Forest of northeastern Minnesota — mountain maple (*Acer spicatum* Lam.), green alder (*Alnus crispa* [(Ait.] Pursh), juneberry (*Amelanchier* Med. [probably *humilis* Wieg.]), beaked hazel (*Corylus cornuta* Marsh.), and willow (*Salix* L. [probably *Bebbiana* Sarg.]) All species were collected from an area that had been clearcut 6 years before except *Acer,* which was collected from a nearby forest.

While still green, all plant material was separated into leaves, current year's woody twig growth (elongation), last year's twig growth, and stem including branches older than 2 years. All components were ovendried at 75C for 48 hours and weighed. The samples were ground to pass a 20-mesh sieve, again dried at 75C for 48 hours, and analyzed.

Ash content was determined by heating in a muffle furnace overnight at 525C. Phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), copper (Cu), zinc (Zn), and manganese (Mn) were determined by dissolving the ash in acidifed LiCl and determining concentrations by emission spectroscopy with a 1.5-m Jarrell-Ash emission spectrometer.[2] Crude protein was determined as ammonium in solution by an ammonia electrode (Bremner and Tabatabai 1972) following micro-Kjeldahl digestion. Caloric content was determined with an adiabatic bomb calorimeter (Parr Inst. Co. 1969), and crude fiber and ether extract were determined by standard procedures (Horowitz 1975). Nitrogen-free extract was determined by difference after determination of the other fractions.

In another study[1], in which we were specifically concerned with snowshoe hare (*Lepus americanus*) browse, we sampled 14 species of young trees and shrubs monthly from November through April in plantations and natural stands in northeastern Minnesota. Stems were returned to the laboratory where their diameter and length were determined. They were then separated into three quality (size) classes and the ovendry weight of material in each class was determined. The three classes were: 0- to 4-mm diameter, centered at 3 mm because most woody stems are larger than 1-mm diameter; 5- to 7-mm diameter, centered at 6 mm; and 8- to 10-mm diameter, centered at 9 mm.

[1]*D.F. Grigal and N.R. Moody. 1979. Estimation of browse by size classes for snowshoe hare. Manuscript submitted to Journal of Wildlife Management.*

[2]*Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.*

After weighing, subsamples of material were ground to pass a 20-mesh sieve and analyzed. Neutral detergent fiber was determined by standard procedures (Van Soest and Wine 1967), and ash, elemental concentrations, crude protein, and caloric content were determined as outlined above.

In our analysis of the data, we determined means and standard errors for each sample type for each month in which a sample was collected. In the data from Ohmann *et al.* (1978), we tested significant differences among monthly means by one way analysis of variance. For leaf elemental concentrations and quality we report overall means in all cases and monthly means where significant differences existed (tables 1 and 2). We report all monthly means whether significantly different or not for current annual growth, because of its importance as browse (tables 3 and 4). We report only overall means for stems because of the limited number of samples (table 5).

For the data from Grigal and Moody[1], we report overall means for each class (table 6). We tested whether or not significant differences existed among classes and we also tested each class on a monthly basis. Monthly differences are reported where we had sufficient samples to satisfy requirements for the tests and where differences were significant (table 7).

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Table 1.—*Elemental concentrations of tall shrub leaves (Ohmann* et al. *1978) —significant differences in monthly values indicated at 0.05 (*) or 0.01 (**) level*

(Standard errors in parentheses)

Species	Month	P	K	Ca	Mg	Fe	Cu	Zn	Mn
		percent dry weight				*mg/kg*			
Mountain maple	All	0.50	1.56	1.27 **	0.05 **	282. *	11.8 **	49.	560.
		(.026)	(.076)	(.094)	(.029)	(12.0)	(.01)	(3.2)	(40.5)
	June	—	—	.79	.38	220.	16.1	—	—
		—	—	(.046)	(.035)	(15.2)	(.01)	—	—
	July	—	—	1.05	.42	296.	13.8	—	—
		—	—	(.118)	(.032)	(28.5)	(.02)	—	—
	Aug.	—	—	1.24	.54	291.	10.0	—	—
		—	—	(.074)	(.034)	(11.0)	(.01)	—	—
	Sept.	—	—	2.02	.64	318.	8.3	—	—
		—	—	(.084)	(.073)	(31.2)	(.01)	—	—
Green alder	All	.23 **	.74 **	.91	.24	239. **	9.1 **	38.	697.
		(.009)	(.034)	(.032)	(.007)	(12.3)	(.55)	(2.4)	(57.2)
	June	.29	.99	—	—	193.	13.0	—	—
		(.010)	(.070)	—	—	(9.7)	(.78)	—	—
	July	.23	.72	—	—	209.	10.3	—	—
		(.011)	(.034)	—	—	(18.6)	(.79)	—	—
	Aug.	.20	.64	—	—	238.	7.3	—	—
		(.012)	(.033)	—	—	(17.1)	(.24)	—	—
	Sept.	.20	.65	—	—	316.	6.9	—	—
		(.007)	(.044)	—	—	(24.9)	(.64)	—	—
Juneberry	All	.45	1.48	1.30 **	.44 *	154. *	11.0 *	72. *	1,327.
		(.025)	(.064)	(.054)	(.013)	(8.1)	(.79)	(3.2)	(70.8)
	June	—	—	1.04	.49	129.	14.7	87.	—
		—	—	(.081)	(.032)	(10.5)	(2.10)	(7.8)	—
	July	—	—	1.16	.48	138.	12.0	62.	—
		—	—	(.118)	(.020)	(11.3)	(1.64)	(4.4)	—
	Aug.	—	—	1.41	.42	152.	9.0	67.	—
		—	—	(.055)	(.015)	(8.6)	(.78)	(4.4)	—
	Sept.	—	—	1.55	.39	198.	9.3	75.	—
		—	—	(.083)	(.029)	(23.2)	(1.15)	(6.9)	—
Beaked hazel	All	.33 *	.86 *	1.48 *	.37 **	288. **	9.6 **	32.	1,779.
		(.012)	(.046)	(.077)	(.013)	(20.8)	(.69)	(6.2)	(113.1)
	June	.37	1.10	1.42	.41	199.	13.2	—	—
		(.024)	(.031)	(.133)	(.029)	(12.5)	(1.19)	—	—
	July	.33	.87	1.29	.38	255.	11.2	—	—
		(.019)	(.051)	(.087)	(.019)	(16.2)	(1.32)	—	—
	Aug.	.29	.79	1.37	.32	304.	7.5	—	—
		(.019)	(.087)	(.089)	(.008)	(31.5)	(.71)	—	—
	Sept.	.36	.70	1.97	.42	406.	7.3	—	—
		(.015)	(.107)	(.228)	(.028)	(59.1)	(.87)	—	—
Willow	All	.31 **	1.05 *	1.21 **	.32	162. *	8.4 **	137. *	536.
		(.030)	(.082)	(.087)	(.015)	(9.3)	(.83)	(18.8)	(96.7)
	June	.50	1.48	.72	—	136.	13.7	209.	—
		(.073)	(.096)	(.093)	—	(11.6)	(1.90)	(39.5)	—
	July	.29	.99	.93	—	155.	8.1	211.	—
		(.026)	(.278)	(.230)	—	(32.3)	(.94)	(60.1)	—
	Aug.	.26	.96	1.47	—	153.	6.4	88.	—
		(.017)	(.131)	(.069)	—	(15.0)	(.62)	(16.9)	—
	Sept.	.21	.79	1.46	—	205.	6.3	100.	—
		(.014)	(.077)	(.136)	—	(13.0)	(.58)	(31.3)	—

Table 2.— *Quality parameters for tall shrub leaves (Ohmann* et al. *1978) — significant differences in monthly values indicated at 0.05 (*) or 0.01 (**) level or not significant (NS)*
(Standard errors in parentheses)

Species	Month	Energy	Ash	Protein	Ether extract	Crude fiber	N-Free extract
		cal/g	*Percent dry weight*				
Mountain maple	All	—	7.4 **	14.1 *	2.8 NS	12.8 NS	62.8 NS
		—	(.29)	(.57)	(.16)	(.21)	(.67)
	June	—	6.4	15.0	3.3	12.9	62.3
		—	(.25)	(.58)	(.36)	(.34)	(.69)
	July	—	6.5	16.7	2.3	13.0	61.5
		—	(.66)	(1.67)	(.46)	(.39)	(2.12)
	Aug.	4,452	7.6	12.6	2.7	12.5	64.6
		(1.9)	(.30)	(.72)	(.13)	(.46)	(1.19)
	Sept.	—	9.1	13.0	3.1	12.8	61.9
		—	(.38)	(.87)	(.31)	(.47)	(.88)
Green alder	All	—	4.4 *	17.0 **	4.8 NS	13.2 NS	60.6 NS
		—	(.15)	(.66)	(.25)	(.29)	(.81)
	June	—	4.2	19.2	4.6	12.1	60.0
		—	(.29)	(.54)	(.66)	(.30)	(1.01)
	July	—	4.1	20.0	4.0	14.0	57.9
		—	(.18)	(1.09)	(.31)	(.54)	(1.48)
	Aug.	4,992	4.3	15.0	4.8	13.0	63.0
		(35.1)	(.24)	(1.09)	(.22)	(.59)	(1.66)
	Sept.	—	5.2	15.0	5.7	13.7	60.4
		—	(.34)	(1.08)	(.72)	(.55)	(1.54)
Beaked hazel	All	—	6.4 **	13.2 **	1.6 **	14.0 **	64.8 NS
		—	(.23)	(.75)	(.18)	(.40)	(.54)
	June	—	6.2	16.7	.60	12.0	64.5
		—	(.34)	(1.40)	(.09)	(.49)	(1.01)
	July	—	5.7	15.9	1.4	14.0	63.1
		—	(.27)	(.47)	(.16)	(.51)	(1.15)
	Aug.	4,513	6.2	11.2	2.3	14.5	65.9
		(21.9)	(.39)	(.92)	(.36)	(.72)	(.96)
	Sept.	—	8.0	9.1	1.6	15.8	65.4
		—	(.32)	(.78)	(.28)	(.57)	(1.02)
Juneberry	All	—	7.0 NS	13.7 **	4.1 *	14.7 NS	60.4 NS
		—	(.15)	(.64)	(.22)	(.33)	(.68)
	June	—	6.7	15.9	3.3	15.0	59.1
		—	(.25)	(.93)	(.33)	(.92)	(1.44)
	July	—	6.7	16.8	3.5	14.7	58.2
		—	(.35)	(.94)	(.36)	(.37)	(1.25)
	Aug.	4,835	7.1	12.0	4.8	14.6	61.6
		(63.2)	(.23)	(.49)	(.42)	(.50)	(.85)
	Sept.	—	7.3	10.8	4.7	14.7	62.5
		—	(.36)	(1.20)	(.30)	(.95)	(1.57)
Willow	All	—	5.3 NS	13.2 **	3.9 NS	12.4 NS	65.3 *
		—	(.15)	(.90)	(.27)	(.32)	(.75)
	June	—	4.9	17.9	3.6	11.4	62.2
		—	(.28)	(1.26)	(.64)	(.42)	(.57)
	July	—	4.7	16.4	3.7	12.4	62.8
		—	(.48)	(2.85)	(1.05)	(1.04)	(3.20)
	Aug.	4,838	5.7	11.5	3.7	12.2	66.9
		(115.4)	(.22)	(.71)	(.23)	(.44)	(.96)
	Sept.	—	5.2	9.4	4.6	13.6	67.2
		—	(.23)	(1.11)	(.69)	(.77)	(1.28)

Table 3.— *Elemental concentrations of tall shrub current twigs (Ohmann* et al. *1978) — significant differences in monthly values indicated at 0.05 (*) or 0.01 (**) level or not significant (NS)*
(Standard errors in parentheses)

Species	Month	P	K	Ca	Mg	Fe	Cu	Zn	Mn
		Percent dry weight				(mg/kg)			
ountain maple	All	.18 **	.83 **	.91 NS	.19 **	48. **	7.8 **	49. NS	332. NS
		(.010)	(.114)	(.025)	(.012)	(3.8)	(.70)	(3.1)	(20.2)
	June	.31	2.24	.82	.30	82.	14.5	53.	376.
		(.024)	(.231)	(.052)	(.036)	(14.1)	(1.83)	(3.8)	(59.6)
	July	.19	1.12	.86	.19	33.	10.1	49.	329.
		(.014)	(.165)	(.061)	(.026)	(4.9)	(.99)	(9.7)	(73.7)
	Aug.	.14	.58	.90	.18	37.	7.2	49.	300.
		(.006)	(.047)	(.062)	(.017)	(3.3)	(.96)	(10.0)	(36.6)
	Sept.	.14	.38	.99	.14	31.	4.5	37.	318.
		(.011)	(.011)	(.061)	(.012)	(3.0)	(.41)	(2.9)	(35.6)
	Oct.	.18	.40	1.03	.16	49.	4.8	50.	396.
		(.006)	(.023)	(.054)	(.011)	(4.4)	(.70)	(6.9)	(62.7)
	Nov.	.16	.40	.88	.17	71.	6.9	56.	298.
		(.013)	(.035)	(.014)	(.021)	(7.3)	(3.70)	(2.9)	(38.4)
	Dec.	.14	.34	.86	.17	51.	5.5	49.	283.
		(.005)	(.017)	(.086)	(.014)	(5.2)	(.75)	(11.6)	(56.8)
een alder	All	.20 **	.50 **	.87 **	.15 **	74. **	9.8 *	57. NS	485. **
		(.013)	(.052)	(.036)	(.010)	(3.9)	(.63)	(3.0)	(41.9)
	June	.36	1.11	1.03	.26	113.	13.0	70.	733.
		(.014)	(.097)	(.055)	(.012)	(5.5)	(2.73)	(6.9)	(94.8)
	July	.25	.68	1.01	.20	70.	12.8	63.	752.
		(.013)	(.042)	(.095)	(.011)	(7.2)	(1.45)	(7.6)	(126.3)
	Aug.	.15	.35	.73	.11	56.	8.6	46.	395.
		(.008)	(.022)	(.049)	(.006)	(5.7)	(.67)	(5.2)	(70.8)
	Sept.	.13	.26	.80	.11	59.	7.6	46.	321.
		(.004)	(.008)	(.032)	(.002)	(5.2)	(.74)	(4.6)	(42.4)
	Oct.	.16	.30	.69	.11	72.	8.7	62.	358.
		(.002)	(.013)	(.043)	(.003)	(7.8)	(.46)	(9.3)	(64.2)
	Nov.	.17	.32	.86	.11	75.	7.3	51.	383.
		(.011)	(.018)	(.172)	(.003)	(6.8)	(.47)	(8.1)	(98.8)
	Dec.	.17	.29	1.10	.11	78.	9.4	71.	389.
		(.014)	(.017)	(.201)	(.003)	(10.3)	(2.28)	(7.7)	(77.0)

(Continued on next page)

(Table 3 continued)

Species	Month	P	K	Ca	Mg	Fe	Cu	Zn	Mn
		Percent dry weight				(mg/kg)			
Beaked hazel	All	.18 **	.80 **	1.21 NS	.18 **	99. **	11.7 NS	63. **	1098. NS
		(.012)	(.046)	(.038)	(.011)	(5.7)	(.47)	(4.5)	(54.0)
	June	.31	1.37	1.25	.31	118.	14.9	107.	1153.
		(.042)	(.138)	(.108)	(.028)	(19.6)	(1.66)	(10.9)	(98.2)
	July	.17	.79	1.21	.22	73.	11.4	62.	1054.
		(.013)	(.045)	(.127)	(.021)	(1.9)	(1.11)	(7.6)	(127.9)
	Aug.	.14	.70	1.09	.15	72.	10.1	45.	990.
		(.007)	(.024)	(.086)	(.007)	(6.7)	(.75)	(4.6)	(108.3)
	Sept.	.16	.66	1.26	.14	115.	12.4	56.	1368.
		(.010)	(.033)	(.059)	(.007)	(15.1)	(1.22)	(6.5)	(235.4)
	Oct.	.16	.63	1.15	.14	113.	10.9	61.	1063.
		(.005)	(.019)	(.043)	(.008)	(12.2)	(.88)	(13.0)	(62.4)
	Nov.	.15	.61	1.15	.12	93.	10.5	56.	897.
		(.011)	(.045)	(.059)	(.007)	(6.1)	(.90)	(14.8)	(54.8)
	Dec.	.16	.74	1.56	.15	139.	12.5	59.	1123.
		(.009)	(.051)	(.023)	(.013)	(12.1)	(.72)	(5.1)	(184.2)
Juneberry	All	.18 **	.61 **	.82 NS	.17 **	34. **	9.7 NS	68. NS	311. NS
		(.014)	(.066)	(.030)	(.008)	(2.7)	(.63)	(3.0)	(18.5)
	June	.35	1.45	.68	.25	26.	13.9	83.	436.
		(.043)	(.153)	(.050)	(.024)	(3.0)	(1.98)	(10.6)	(46.5)
	July	.17	.72	.72	.16	26.	10.2	56.	302.
		(.018)	(.080)	(.028)	(.009)	(7.6)	(1.84)	(4.6)	(48.1)
	Aug.	.13	.40	.86	.14	25.	8.8	65.	303.
		(.008)	(.010)	(.065)	(.012)	(3.9)	(1.11)	(4.9)	(40.3)
	Sept.	.14	.38	.86	.15	29.	9.6	62.	246.
		(.006)	(.028)	(.082)	(.014)	(4.2)	(1.29)	(3.0)	(37.6)
	Oct.	.18	.41	.88	.17	44.	9.6	77.	300.
		(.009)	(.045)	(.064)	(.007)	(3.8)	(.97)	(8.9)	(47.3)
	Nov.	.16	.46	.98	.13	58.	6.0	65.	258.
		(.004)	(.027)	(.234)	(.006)	(10.4)	(2.24)	(19.2)	(47.5)
	Dec.	.18	.36	.85	.16	62.	7.2	66.	302.
		(.010)	(.018)	(.036)	(.005)	(2.3)	(.40)	(3.2)	(29.1)
Willow	All	.20 **	.72 **	.80 NS	.13 **	124. NS	9.6 *	164. NS	215. NS
		(.019)	(.117)	(.029)	(.009)	(20.0)	(.75)	(12.7)	(38.4)
	June	.42	2.16	.86	.22	69.	14.5	219.	303.
		(.063)	(.234)	(.093)	(.024)	(7.4)	(.96)	(45.4)	(156.0)
	July	.18	.70	.75	.15	51.	12.4	233.	483.
		(.014)	(.051)	(.110)	(.030)	(8.6)	(1.44)	(77.5)	(328.4)
	Aug.	.14	.53	.84	.11	78.	9.8	114.	129.
		(.011)	(.065)	(.047)	(.011)	(16.3)	(2.11)	(9.5)	(25.1)
	Sept.	.15	.38	.76	.10	193.	7.9	141.	150.
		(.012)	(.022)	(.065)	(.006)	(102.4)	(.98)	(19.4)	(20.4)
	Oct.	.17	.31	.76	.11	157.8	6.7	170.	201.
		(.006)	(.011)	(.072)	(.006)	(29.5)	(.37)	(18.6)	(26.0)
	Nov.	.18	.34	.82	.10	167.	6.3	147.	222.
		(.021)	(.005)	(.127)	(.008)	(23.2)	(2.54)	(29.2)	(87.2)
	Dec.	.16	.31	.75	.09	192.	8.7	183.	180.
		(.011)	(.003)	(.129)	(.007)	(70.5)	(.34)	(45.4)	(12.3)

Table 4.— *Quality parameters for tall shrub current twigs (Ohmann et al. 1978) — significant differences in monthly values indicated at 0.05 (*) or 0.01 (**) level or not significant (NS) (Standard errors in parentheses)*

Species	Month	Energy	Ash	Protein	Ether extract	Crude fiber	N-free extract
		cal/g	*Percent dry weight*				
ountain maple	All	4,662 *	3.5 **	6.2 **	2.0 NS	36.8 *	51.4 NS
		(40.2)	(.19)	(.38)	(.09)	(.77)	(.49)
	June	4,518	6.4	10.6	1.7	29.0	52.5
		(13.5)	(.37)	(2.77)	(.13)	(1.71)	(1.14)
	July	4,638	4.0	7.3	2.0	35.9	50.7
		(19.6)	(.28)	(.44)	(.15)	(2.16)	(1.68)
	Aug.	4,628	3.4	5.1	2.0	37.9	51.6
		(41.8)	(.21)	(.38)	(.20)	(1.31)	(.92)
	Sept.	4,680	3.0	5.0	2.2	39.0	50.8
		(39.7)	(.18)	(.38)	(.20)	(1.73)	(1.36)
	Oct.	4,687	3.1	6.0	2.2	36.4	52.2
		(2.1)	(.23)	(.50)	(.32)	(1.57)	(1.17)
	Nov.	[1] 4,705	3.5	6.4	1.3	37.3	51.5
		—	(.07)	(.98)	(.07)	(1.46)	(1.50)
	Dec.	4,746	2.2	4.9	2.5	39.3	51.0
		(28.6)	(.18)	(.07)	(.09)	(2.28)	(2.37)
een alder	All	5,091 **	3.1 **	9.2 **	5.7 **	21.9 *	60.1 NS
		(51.9)	(.22)	(.24)	(.37)	(.38)	(.35)
	June	4,766	6.2	11.4	2.9	18.6	60.9
		(6.5)	(.83)	(.56)	(.69)	(2.60)	(3.0)
	July	4,802	3.9	10.5	2.9	22.3	60.4
		(61.5)	(.33)	(1.17)	(.21)	(.93)	(.72)
	Aug.	5,054	2.6	8.7	5.2	23.6	59.8
		(56.3)	(.19)	(.17)	(.49)	(.60)	(.62)
	Sept.	5,159	2.5	8.4	7.8	21.3	60.1
		(19.3)	(.09)	(.21)	(.52)	(.45)	(.62)
	Oct.	5,174	2.2	9.2	6.5	22.0	60.1
		(35.5)	(.20)	(.31)	(.35)	(.65)	(.63)
	Nov.	[1]5,189	3.0	8.4	6.0	21.3	61.3
		—	(.37)	(.37)	(.27)	(.57)	(.72)
	Dec.	5,181	2.7	8.9	8.8	21.6	57.9
		(33.2)	(.38)	(.11)	(.38)	(.99)	(.82)
aked hazel	All	4,546 **	4.2 NS	7.0 **	1.9 **	24.6 NS	62.2 NS
		(34.1)	(.11)	(.31)	(.10)	(.35)	(.44)
	June	4,314	5.1	10.3	.82	23.2	60.6
		(64.0)	(.27)	(2.47)	(.28)	(1.62)	(.29)
	July	4,496	4.3	8.9	1.4	25.2	60.2
		(50.0)	(.37)	(.89)	(.21)	(1.19)	(2.06)
	Aug.	4,530	3.9	6.0	2.2	24.6	63.3
		(22.2)	(.26)	(.40)	(.20)	(.79)	(.66)
	Sept.	4,624	4.3	6.3	2.2	24.1	63.2
		(9.9)	(.17)	(.36)	(.11)	(.81)	(.81)
	Oct.	4,549	4.2	7.3	2.1	25.6	60.8
		(11.0)	(.20)	(.22)	(.22)	(.72)	(.56)
	Nov.	[1]4,652	4.5	6.8	1.7	24.0	63.0
		—	(.36)	(.41)	(.13)	(.60)	(.68)
	Dec.	4,622	4.4	6.0	1.9	23.7	64.1
		(12.0)	(.02)	(.16)	(.18)	(.63)	(.69)

(Continued on next page)

(Table 4 continued)

Species	Month	Energy	Ash	Protein	Ether extract	Crude fiber	N-free extract
		cal/g	*Percent dry weight*				
Juneberry	All	4,715 **	3.1 **	6.1 **	2.2 **	29.7 NS	58.9 *
		(35.1)	(.12)	(.35)	(.16)	(.56)	(.61)
	June	4,588	4.4	12.2	1.6	27.7	54.1
		(51.0)	(.03)	(3.06)	(.25)	(.17)	(2.62)
	July	4,661	3.1	6.1	2.3	32.8	55.7
		(26.5)	(.17)	(.61)	(.23)	(1.56)	(2.12)
	Aug.	4,668	2.9	4.7	1.9	29.3	61.1
		(25.8)	(.19)	(.34)	(.30)	(1.26)	(1.09)
	Sept.	4,724	2.8	5.6	2.2	30.2	59.2
		(22.4)	(.18)	(.27)	(.21)	(.67)	(.45)
	Oct.	4,758	3.1	6.8	1.9	29.4	58.8
		(10.0)	(.12)	(.19)	(.20)	(1.42)	(1.06)
	Nov.	[1]4,829	4.2	5.4	1.7	27.0	61.6
		—	(.58)	(.19)	(.58)	(2.12)	(1.13)
	Dec.	4,851	2.6	6.4	4.2	28.8	58.0
		(15.7)	(.02)	(.20)	(.36)	(1.02)	(1.23)
Willow	All	4,995 **	3.3 **	6.6 **	3.2 **	30.7 **	56.2 NS
		(52.8)	(.21)	(.30)	(.16)	(.60)	(.41)
	June	4,740	6.2	9.7	2.1	23.8	58.3
		(30.6)	(.43)	(1.14)	(.18)	(1.16)	(1.47)
	July	4,814	3.2	7.9	2.7	28.9	57.3
		—	(.24)	(.96)	(.34)	(1.34)	(2.33)
	Aug.	4,942	3.2	5.3	2.9	32.5	56.1
		(79.8)	(.21)	(.32)	(.26)	(.58)	(.44)
	Sept.	5,064	2.7	5.9	3.7	32.2	55.5
		(15.0)	(.25)	(.42)	(.21)	(.93)	(.86)
	Oct.	5,096	2.7	6.9	3.7	31.9	54.8
		(54.0)	(.13)	(.22)	(.23)	(1.09)	(.85)
	Nov.	[1]5,100	3.2	6.7	2.8	31.7	55.6
		—	(.33)	(.46)	(.21)	(1.42)	(2.24)
	Dec.	5,094	2.1	6.3	4.8	29.6	57.3
		(15.4)	(.28)	(.31)	(.22)	(1.42)	(1.06)

[1]No standard error calculated because energy values are based on single sample

Table 5.—*Elemental concentrations of tall shrub stems (Ohmann* et al. *1978)*
(Standard errors in parentheses)

Species	Month	P	K	Ca	Mg	Fe	Cu	Zn	Mn
		percent dry weight				*mg/kg*			
Mountain maple	All	.04	.14	.34	.05	35	3.1	23	106
		(.002)	(.006)	(.012)	(.002)	(1.5)	(.20)	(1.2)	(8.7)
Green alder	All	.06	.14	.38	.05	58	5.1	41	152
		(.003)	(.006)	(.018)	(.002)	(4.0)	(.29)	(3.5)	(12.6)
Beaked hazel	All	.08	.22	.61	.05	79	6.4	46	447
		(.004)	(.006)	(.021)	(.002)	(3.9)	(.30)	(5.3)	(25.3)
Juneberry	All	.06	.17	.41	.05	46	6.3	40	159
		(.003)	(.008)	(.016)	(.002)	(4.8)	(.40)	(2.2)	(11.1)
Willow	All	.06	.14	.58	.05	34	5.0	86	85
		(.002)	(.007)	(.027)	(.018)	(2.4)	(.26)	(5.4)	(7.8)

Table 6.— *Quality parameters and elemental concentrations of tall shrub and tree twigs (Grigal and Moody)— significant differences in size classes indicated at 0.05 (*) or 0.01 (**) level or not significant (NS)* (Standard error in parentheses).

ecies	Size	Energy	Fiber	Ash	Protein	P	K	Ca	Mg	Fe	Cu	Zn	Mn
	mm	(cal/g)	Percent dry weight							mg/kg			
d maple													
cer rubrum)	≤ 4	4,523 NS	58 **	3.1 NS	7.7 NS	.15**	.38 *	1.00**	.10**	64 *	5.6**	39 NS	424 NS
		(44.5)	(0.9)	(.24)	(.89)	(.019)	(.044)	(.087)	(.004)	(10.1)	(.55)	(8.9)	(141.6)
	5 to 7	4,567	67	2.6	6.6	.09	.32	.74	08	45	4.6	30	332
		(56.5)	(2.3)	(.12)	(.44)	(.006)	(.035)	(.048)	(.003)	(4.3)	(.18)	(4.9)	(98.9)
	8 to 10	4,531	81	1.7	6.8	.06	.21	.41	.05	22	3.1	20	198
		(42.5)	(0.8)	(.38)	(1.10)	(.001)	(.025)	(.061)	(.002)	(4.7)	(.30)	(6.0)	(72.6)
untain maple													
	≤ 4	4,762 *	59 **	4.2**	7.1 NS	12**	.37**	1.39**	.12**	81 **	4 4 NS	61 **	276 **
		(89.2)	(1.2)	(.21)	(.55)	(.005)	(009)	(.053)	(.004)	(10.9)	(.28)	(5.4)	(22.1)
	5 to 7	4,573	68	2.8	5.9	.08	26	96	.07	52	4.2	43	165
		(54.5)	(0.7)	(.15)	(.21)	(.004)	(.008)	(.042)	(.003)	(8.4)	(.59)	(2.8)	(17.7)
	8 to 10	4,521	76	2.1	5.9	06	.20	.70	.05	37	3.3	33	125
		(36.9)	(2.1)	(.06)	(.39)	(.003)	(.007)	(.026)	(.003)	(6.8)	(.37)	(1.7)	(13.3)
een alder													
	≤ 4	4,873 NS	58 NS	3.0 NS	8.5 NS	12 *	.29**	.97 NS	.11**	85 NS	7.7**	54 NS	138 NS
		(45.5)	(3.1)	(.34)	(.44)	(.013)	(.025)	(.123)	(.009)	(17.0)	(.45)	(14.7)	(29.0)
	5 to 7	4,758	65	2.3	6.8	.09	.21	.71	.07	68	5.1	38	89
		(45.3)	(4.0)	(.35)	(.43)	(.008)	(.011)	(.094)	(.001)	(19.0)	(.56)	(12.3)	(16.5)
	8 to 10	4,738	68	2.1	6.7	08	.18	.65	.07	63	4.6	37	75
		(48.3)	(2.0)	(.40)	(.65)	(.009)	(.013)	(.095)	(.002)	(14.8)	(.35)	(12.3)	(15.1)
eckled alder													
Inus rugosa)	≤ 4	5,024 NS	59 **	2.6**	9.3**	.11**	.31**	.76 NS	.12**	125 NS	10.8**	121 **	235 NS
		(79.6)	(1.5)	(.13)	(.48)	(.006)	(.018)	(.068)	(.005)	(8.1)	(.81)	(6.7)	(31.4)
	5 to 7	4,918	65	2.1	7.1	.08	.24	63	.08	106	6.7	89	199
		(55.8)	(1.8)	(.11)	(.37)	(.004)	(.012)	(.046)	(.003)	(13.2)	(.47)	(9.5)	(20.2)
	8 to 10	4,811	70	1.8	6.1	.07	.22	.61	.08	105	5.3	75	213
		(56.8)	(1.4)	(.07)	(.57)	(.006)	(.016)	(.058)	(.004)	(16.6)	(.35)	(12.6)	(34.9)
neberry													
	≤ 4	4,778 **	67 **	2.9 NS	7 1 NS	10 NS	.34 *	89 NS	.12**	71 **	8 2 *	64 NS	138 NS
		(22.0)	(1.6)	(.39)	(.58)	(.015)	(.035)	(.137)	(.015)	(4.7)	(.92)	(8.8)	(40.3)
	5 to 7	4,641	77	2.3	5.9	.08	.28	.71	.09	47	6.9	43	89
		(35.3)	(2.1)	(.35)	(.17)	(.014)	(031)	(.121)	(.009)	(4.8)	(.71)	(7.3)	(38.3)
	8 to 10	4,479	82	1.8	6.1	.06	22	.57	06	39	5.2	39	82
		(37.3)	(1.1)	(.12)	(.13)	(.011)	(.021)	(.031)	(.004)	(2.9)	(.35)	(7.5)	(38.9)
g birch													
Betula pumila)	≤ 4	4,940 **	69 NS	1 8**	7.7 NS	09**	.22 *	47 NS	.10**	227 **	6 3 NS	240 **	162 NS
		(30.4)	(1.3)	(.10)	(.91)	(.006)	(.011)	(.042)	(.007)	(34.8)	(.35)	(19.9)	(18.7)
	5 to 7	4,770	77	1.5	6.6	.07	.17	.35	.08	132	4.7	179	123
		(31.3)	(2.1)	(.18)	(.40)	(.005)	(.009)	(.035)	(.004)	(21.4)	(.55)	(14.2)	(16.2)
	8 to 10	4,761	77	1.1	6.5	.06	.16	36	.07	115	5.3	161	104
		(28.0)	(4.3)	(.06)	(.75)	(.006)	(.020)	(.064)	(.009)	(15.3)	(1.39)	(10.6)	(16.5)
gwoods													
Cornus spp.)	≤ 4	4,662 *	56 **	3.8**	6.5 NS	14 NS	.33**	1.26**	10**	70 *	5 7 NS	38 **	28 NS
		(87.4)	(2.1)	(.19)	(.69)	(.018)	(017)	(.083)	(.008)	(7.0)	(.74)	(7.0)	(7.8)
	5 to 7	4,543	63	3.0	6.2	13	28	1.02	.07	44	4.5	20	15
		(23.5)	(2.5)	(.16)	(.68)	(.019)	(.019)	(.050)	(.006)	(5.1)	(.63)	(2.9)	(6 6)
	8 to 10	4,378	67	2.2	5.3	.11	23	.79	05	40	5.2	15	11
		(89.3)	(2.1)	(.25)	(.91)	(.022)	(017)	(.056)	(.006)	(9.9)	(1.85)	(4.0)	(4.7)
aked hazel													
	≤ 4	4,535 NS	64 **	4.5**	7 0 NS	11**	.53**	1.29**	.12**	122 **	8.9**	65 **	495 **
		(17.2)	(1.2)	(.12)	(.36)	(.005)	(.024)	(.056)	(.005)	(6.9)	(.76)	(5.3)	(59.3)
	5 to 7	4,503	76	3.4	6.2	08	.31	1.01	08	101	6.4	38	279
		(49.4)	(1.1)	(.13)	(.22)	(.005)	(012)	(.052)	(.003)	(8.7)	(.69)	(3.6)	(37.3)
	8 to 10	4,501	78	2.7	6.5	07	23	85	06	62	4.5	21	235
		(26.6)	(2.1)	(.15)	(.37)	(.003)	(009)	(.048)	(.002)	(5.1)	(.25)	(4.1)	(28.8)

(Continued on next page)

(Table 6 continued)

Species	Size	Energy	Fiber	Ash	Protein	P	K	Ca	Mg	Fe	Cu	Zn	Mn
	mm	(cal/g)	Percent dry weight							mg/kg			
Quaking aspen (*Populus tremuloides*)	≤4	4,566 NS	69 *	4.1 NS	9.4 NS	.12 *	.34 NS	1.32 NS	.12 **	79 NS	8.5 NS	29 NS	77 *
		(40.2)	(2.6)	(.46)	(2.08)	(.006)	(.033)	(.140)	(.003)	(11.4)	(.99)	(5.7)	(16.8)
	5 to 7	4,537	76	3.5	7.6	.10	.26	.92	.08	60	6.0	23	43
		(29.5)	(0.8)	(1.08)	(1.95)	(.015)	(.061)	(.297)	(.014)	(3.8)	(1.27)	(5.0)	(2.2)
	8 to 10	4,548	81	2.1	6.0	.07	.19	.55	.05	42	3.9	18	28
		(15.3)	(2.2)	(.20)	(1.16)	(.003)	(.029)	(.059)	(.002)	(7.3)	(.84)	(4.8)	(6.7)
Willow													
	≤4	4,909 NS	59 **	2.1 NS	9.2 NS	.13 *	.28 NS	.44 NS	.17 *	70 NS	7.3 NS	231 NS	551 NS
		(73.9)	(0.4)	(.05)	(.93)	(.010)	(.018)	(.049)	(.006)	(5.5)	(1.45)	(22.4)	(104.4)
	5 to 7	4,779	66	1.9	7.5	.11	23	.41	.14	68	5.3	199	578
		(100.6)	(1 1)	(.02)	(.79)	(.008)	(.020)	(.026)	(.011)	(7.4)	(.95)	(19.8)	(86.2)
	8 to 10	4,759	71	1.9	6.9	.08	.20	.36	.12	52	5.2	166	494
		(34.5)	(1 9)	(.16)	(.57)	(.013)	(.035)	(.033)	(.015)	(10.5)	(.69)	(19.3)	(79.3)

Table 7.— *Quality parameters and elemental concentrations of tall shrub twigs (Grigal and Moody)*
(Standard errors in parentheses)

Species	Size	Parameter	Dec	Jan	Feb	Mar
	(mm)					
Mountain maple	5 to 7	K (% dry wt)	[1].21	.28	.26	.25
			(.005)	(.008)	(.001)	(.010)
	8 to 10	P (% dry wt)	[2].05	.07	.07	.07
			(.001)	(.003)	(.005)	(.002)
	8 to 10	Fe (mg/kg)	[2]15.	36.	79.	21.
			(.5)	(4.1)	(34.5)	(8.0)
	8 to 10	Cu (mg/kg)	[1]2.6	3.9	4.0	0.9
			(.65)	(.35)	(.25)	(.05)
Beaked hazel	≤4	Fiber (% dry wt)	[2]68.	66.	59.	61.
			(0.6)	(2.1)	(1.5)	(0.7)
	≤4	P (% dry wt)	[2]0.10	0.10	0.12	0.15
			(.005)	(.005)	(.008)	(.025)
	≤4	Fe (mg/kg)	[2]89.	138.	98.	114.
			(8.8)	(8.2)	(2.1)	(6.8)
	5 to 7	P (% dry wt)	[2].07	.08	.11	.11
			(.006)	(.005)	(.012)	(.031)
	5 to 7	K (% dry wt)	[2].30	.31	.40	.27
			(.013)	(.013)	(.061)	(.015)
	5 to 7	Fe (mg/kg)	[2].62	119.	76.	86.
			(9.3)	(11.2)	(13.6)	(22.6)
	8 to 10	Protein (% dry wt)	[2]5.3	6.9	8.2	4.6
			(.05)	(.49)	(.37)	(.57)
	8 to 10	Fe (mg/kg)	[2]30.	72.	63.	56.
			(3.0)	(6.8)	(4.6)	(3.2)

[1]Significant differences in monthly values indicated at 0.01 level.
[2]Significant differences in monthly values indicated at 0.05 level.

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SITE INDEX COMPARISONS AMONG NORTHERN HARDWOODS IN NORTHERN WISCONSIN AND UPPER MICHIGAN

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SITE INDEX COMPARISONS AMONG NORTHERN HARDWOODS IN NORTHERN WISCONSIN AND UPPER MICHIGAN

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Northern hardwoods are the principal species
und in many of the more important and wide-
read forest types of the United States and Cana-
. Forest types composed primarily of northern
rdwood species cover about 37 million acres in
e Lake States, the Northeast, and the Appala-
ian Plateau (USDA Forest Service 1973); in
nada, hardwood and mixedwood stands cover
out 74 million acres (Quigley and Babcock
69). Characteristic species in the Lake States
e sugar maple (*Acer saccharum* Marsh.), red ma-
e (*A. rubrum* L.), and yellow birch (*Betula alle-
aniensis* Britton). In certain areas American
ech (*Fagus grandifolia* Ehrh.), American bass-
od (*Tilia americana* L.), American elm (*Ulmus
nericana* L.), and white ash (*Fraxinus americana*
) are important stand components. Other associ-
ed species that occur less frequently are black
h (*F. nigra* Marsh.), black cherry (*Prunus sero-
a* Ehrh.), northern red oak (*Quercus rubra* L.),
per birch (*B. papyrifera* Marsh.), quaking aspen
opulus tremuloides Michx.), and bigtooth aspen
grandidentata Michx.).[1]

Because of this profusion of species in northern
rdwood forests, forest managers often are uncer-
in about which tree species to favor on a given
ea of land. For each site, species may differ in
te of growth and in volume and value of yield
oduced. Selecting the most desirable tree species
each site is a problem frequently encountered
timber stand improvement, thinning, final har-
st prescriptions, stand conversion, and tree
anting.

Site index is the most widely accepted method
estimating site quality in the United States
d is based on age and height measurements
ken from free growing, uninjured, dominant and
codominant trees (Carmean 1975, 1977). Such trees are most commonly found in even-aged, fully stocked stands not severely disturbed by past logging. Even-aged, fully stocked, second-growth stands are common throughout the range of northern hardwood species; they developed following the removal of the original old growth stands by clearcutting or heavy harvest cutting. Dominant and codominant trees in these even-aged hardwood stands are well suited for site index estimation. Site index can now be estimated for northern hardwoods using recently published site curves for 13 species commonly found in the northern hardwood stands of northern Wisconsin and Upper Michigan (Carmean 1978).

Selecting the most desirable northern hardwood tree for each site not only requires accurate site information for each species of tree but also detailed information about site relations among the various hardwood species that might be considered for management. On a certain site should we favor yellow birch, black cherry, and white ash for veneer and high value log production, or should we manage aspen on short rotations? When a forest manager knows the site index for several alternative species he can then estimate the yield attained for each tree species. Such site and yield information provides a means for estimating and comparing the volume and value of wood products that different sites are capable of producing when stocked with these alternative tree species.

Even when site index curves are available northern hardwood stands rarely have measurable trees of all species for which site information is desired. For such stands site index of the absent species can be estimated from the site index of species that are present through the use of site index comparison graphs or equations (Curtis and

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ree names follow Little (1953).

Post 1962, Foster 1959, Carmean and Vasilevsky 1971). No site index comparison studies are available for the northern hardwood species commonly found in the Lake States. Accordingly, this site index comparison study was made for hardwood species commonly found in even-aged northern hardwood stands of northern Wisconsin and Upper Michigan.

THE DATA

This site index comparison study is based on data collected from 204 plots established in or near the Chequamegon, Nicolet, Ottawa, and Hiawatha National Forests in northern Wisconsin and Upper Michigan. All plots were approximately 1/5-acre and were located in fully stocked, even-aged, undisturbed northern hardwood stands between 41 and 105 years of age; trees on each plot had a range in age no greater than 10 years. Several tree species usually occurred on each plot, and one to six dominant or codominant site trees of each species were felled. Sections were cut at a 6-inch stump height, at 2 feet, at 4.5 feet, and at 4-foot intervals thereafter up the bole; annual rings were carefully counted from disks cut at each section point.

Individual tree height-age curves were plotted using age counts at each section point. Trees with signs of early suppression, top breakage, or dieback, or that exceeded the defined 10 year age range for even-aged stands were deleted from the data. A total of 3,402 dominant and codominant trees were retained for computing site index curves for 13 species (Carmean 1978). For each species on each plot the individual tree height-age curves were combined into an average height-age curve. Site index (height at 50 years) for each species on each plot was then read directly from these average height-age curves. Most plots had site index estimates for at least two species, and a few plots had estimates for as many as eight. Site index values were recorded for all paired species combinations found on each plot (table 1). Species pairs such as sugar maple-yellow birch and sugar maple-American basswood were found on a large number of plots. In contrast, some species such as American beech, black cherry, paper birch, and the aspens were less common and paired combinations of them were rarely encountered.

ANALYSIS AND RESULTS

Scatter diagrams for 51 paired species combinations were made that compared site indices of the two paired species (table 1). This preliminary plotting revealed that certain species pairs were distinctly different and other species pairs were similar in site index. The scatter diagrams indicated that northern hardwood species, when growing together on the same plot, can be placed in four

Table 1.—*Species site-index comparisons were based on site index measurements for all possible species pairs found on 204 site plots located in northern Wisconsin and Upper Michigan*

Species	RM	YB	AB	B	E	WA	BA	NRO	BC	PB	A
	number of plots having paired observations										
Sugar maple (SM)	89	109	19	109	94	59	27	26	36	23	7
Red maple (RM)		71	13	45	39	30	19	23	33	16	8
Yellow birch (YB)			15	70	60	37	20	14	25	16	7
American beech (AB)				[1](4)	(3)	(3)	(0)	(1)	(6)	(2)	(0)
American basswood (B)					86	64	31	29	15	20	8
American elm (E)						51	34	15	16	12	7
White ash (WA)							27	22	(6)	9	7
Black ash (BA)								10	(1)	(3)	(3)
Northern red oak (NRO)									(6)	15	7
Black cherry (BC)										(5)	(1)
Paper birch (PB)											7
Aspens (A)											

[1]Numbers in parentheses are for those species pairs having too few plots for regression analyses.

neral site index groupings: (a) *very high site* - pens; (b) *high site* - white ash, American bass- ood, American elm, black ash, black cherry, rthern red oak, and paper birch, (c) *medium site* ugar maple, red maple, and yellow birch, and (d) *v site* - American beech.

No curvilinear trends appeared, so linear re- ession equations were computed for each species ir using site index of one species as the depen- nt variable and site index of the other species as e independent variable. Because either of the ecies can be used as the dependent variable, two parate equations were computed for each of the ecies pairs (table 2). The resulting equations counted for from 38 to 91 percent (r^2) of the riation in site index of the dependent variable sociated with the various species pairs.

The two computed equations for each species ir are the most precise means for directly calcu- ting site index of one species based on measured e index of an associated species (table 2). How- er, when making such calculations the equa- ns should be used only to estimate site index of e dependent and not site index of the indepen- nt variable—that is, the equations should only solved forward and not backward. One of the als of this study is to construct site index com- rison graphs that can be used to convert site dex measured from species present in the stand site index of other species that are absent. For nvenience we should be able to use such graphs rward or backward to estimate site index of ei- er of the paired species. So a third equation was termined graphically that averaged the two uations computed for each of the species pairs ble 2) (Carmean and Vasilevsky 1971).

Group Combinations

Preliminary plotting had indicated that site in- ces for several species pairs were similar, thus e next step in computation was to group the ecies with similar site indices and regressions. end graphs were plotted using the average re- ession equations for each of the 51 species pairs. ese graphs were then used to observe the mag- tude of the site index differences between the o paired species. The regression coefficients of e two computed equations and their associated andard errors were also examined to determine significant differences existed between regres- ns for the two paired species.

This examination of graphs and regression coef- ficients confirmed the initial general species groupings observed by the preliminary plotting. Also an additional 4 groupings were found among the 7 "high site" species (table 3). On each plot, species within each group were combined to obtain a weighted average site index for the group. Lin- ear regressions were then computed for 14 group pairs (table 4). A graphically determined average equation also was obtained for each of the 14 group pairs based on the two computed equations.

For each species or group pair the most precise site index estimates can be made using either of the two computed equations (tables 2 and 4). But site index estimates from the graphically deter- mined average equations are similar to values estimated using either of the two computed equa- tions; similar site index estimates are most likely for medium levels of site index and when the two computed equations do not differ greatly. The gra- phically determined average equations are conve- nient because they can be solved forward or backward and thus are suited for calculating spe- cies site index comparison graphs.

The average equations can be used to calculate individual site index comparison graphs for any of the species pairs (table 2) or group pairs (table 4). However, a single graph combining all 13 species is most convenient for field use; also a single graph can better illustrate differences in site index be- tween tree species at different levels of site qual- ity. Accordingly, the average equations for the group pairs were used to construct a graph that compared site indices among all 13 species (fig. 1). This comparison graph was calculated using the six average equations where predicted site index is the weighted average combining sugar maple, red maple, and yellow birch; similar trends are pre- dicted by the other eight equations that use other species groups as the dependent variable (table 4). Trend lines of this graph are restricted to the range of site index observed on the plots and also to the range in which site indices differ by no more than 5 feet when calculated by either of the two computed equations.

Site Relations and Soil Drainage

The previous analyses showed that the regres- sion equations accounted for from 38 to 91 percent

Table 2.—*Regression equations relating site index between all possible species pairs among northern hardwood species (also given are equations that average the trends of the two equations listed for each species pair)*

Species comparisons	Paired observations	Site index range	Equations	Coefficient of determination (r^2)	Standard error of estimate
	No.	feet			feet
Sugar maple	89	42-74	$^1SI_{SM} = 3.336+0.930\ (SI_{RM})$	0.79	3.14
Red maple	89	42-73	$^1SI_{RM} = 9.362+0.851\ (SI_{SM})$	0.79	3.00
			$SI_{SM} = -3.563+1.048\ (SI_{RM})$		
Sugar maple	109	42-75	$^1SI_{SM} = 6.787+0.885\ (SI_{YB})$	0.73	3.66
Yellow birch	109	40-76	$^1SI_{YB} = 10.327+0.825\ (SI_{SM})$	0.73	3.53
			$SI_{SM} = -2.119+1.036\ (SI_{YB})$		
Sugar maple	19	47-65	$SI_{SM} = 25.063+0.611\ (SI_{AB})$	0.38	3.86
Am. beech	19	45-61	$SI_{AB} = 17.057+0.628\ (SI_{SM})$	0.38	3.91
			$SI_{SM} = 4.902+0.989\ (SI_{AB})$		
Sugar maple	109	42-75	$^1SI_{SM} = 6.299+0.832\ (SI_{B})$	0.68	3.77
Am. basswood	109	45-80	$^1SI_{B} = 15.101+0.821\ (SI_{SM})$	0.68	3.74
			$SI_{SM} = -4.970+1.008\ (SI_{B})$		
Sugar maple	94	43-75	$^1SI_{SM} = 10.609+0.766\ (SI_{E})$	0.71	3.52
Am. elm	94	47-81	$^1SI_{E} = 8.840+0.925\ (SI_{SM})$	0.71	3.87
			$SI_{SM} = 1.262+0.912\ (SI_{E})$		
Sugar maple	59	42-75	$SI_{SM} = 11.189+0.728\ (SI_{WA})$	0.69	3.88
White ash	59	46-84	$SI_{WA} = 10.572+0.941\ (SI_{SM})$	0.69	4.41
			$SI_{SM} = 1.006+0.880\ (SI_{WA})$		
Sugar maple	27	42-70	$SI_{SM} = 7.706+0.801\ (SI_{BA})$	0.60	4.48
Black ash	27	52-78	$SI_{BA} = 20.285+0.743\ (SI_{SM})$	0.60	4.31
			$SI_{SM} = -7.746+1.041\ (SI_{BA})$		
Sugar maple	26	42-70	$SI_{SM} = 0.906+0.885\ (SI_{NRO})$	0.44	4.23
N. red oak	26	57-72	$SI_{NRO} = 35.432+0.493\ (SI_{SM})$	0.44	3.16
			$SI_{SM} = -25.774+1.304\ (SI_{NRO})$		
Sugar maple	36	42-68	$SI_{SM} = 14.384+0.729\ (SI_{BC})$	0.73	3.22
Black cherry	36	47-73	$SI_{BC} = 2.176+1.000\ (SI_{SM})$	0.73	3.77
			$SI_{SM} = 6.752+0.854\ (SI_{BC})$		
Sugar maple	23	43-69	$SI_{SM} = 6.306+0.809\ (SI_{PB})$	0.59	4.24
Paper birch	23	47-72	$SI_{PB} = 21.018+0.726\ (SI_{SM})$	0.59	4.24
			$SI_{SM} = -8.975+1.055\ (SI_{PB})$		
Sugar maple	7	42-75	$SI_{SM} = 2.624+0.780\ (SI_{A})$	0.61	7.82
Aspens	7	65-85	$SI_{A} = 25.430+0.776\ (SI_{SM})$	0.61	7.81
			$SI_{SM} = -12.575+0.998\ (SI_{A})$		
Red maple	71	42-73	$SI_{RM} = 7.837+0.876\ (SI_{YB})$	0.70	3.60
Yellow birch	71	40-72	$SI_{YB} = 10.943+0.802\ (SI_{RM})$	0.70	3.44
			$SI_{RM} = -2.119+1.048\ (SI_{YB})$		
Red maple	13	50-63	$SI_{RM} = 28.555+0.547\ (SI_{AB})$	0.38	3.47
Am. beech	13	45-60	$SI_{AB} = 13.616+0.688\ (SI_{RM})$	0.38	3.89
			$SI_{RM} = 9.510+0.904\ (SI_{AB})$		
Red maple	45	43-72	$SI_{RM} = 4.068+0.881\ (SI_{B})$	0.79	3.40
Am. basswood	45	45-74	$SI_{B} = 9.417+0.892\ (SI_{RM})$	0.79	3.42
			$SI_{RM} = -2.628+0.991\ (SI_{B})$		

(Table 2 continued on next page)

(Table 2 continued)

ecies mparisons	Paired observations	Site index range	Equations	Coefficient of determination (r^2)	Standard error of estimate
d maple	39	46-71	$SI_{RM} = 19.926+0.628\ (SI_E)$	0.56	4.09
n. elm	39	47-76	$SI_E = 8.686+0.899\ (SI_{RM})$	0.56	4.90
			$SI_{RM} = 6.729+0.844\ (SI_E)$		
d maple	30	46-70	$SI_{RM} = 21.977+0.593\ (SI_{WA})$	0.63	4.02
hite ash	30	44-76	$SI_{WA} = 0.017+1.065\ (SI_{RM})$	0.63	5.39
			$SI_{RM} = 11.937+0.751\ (SI_{WA})$		
d maple	19	43-68	$SI_{RM} = 5.616+0.870\ (SI_{BA})$	0.60	4.42
ack ash	19	51-70	$SI_{BA} = 20.283+0.688\ (SI_{RM})$	0.60	3.93
			$SI_{RM} = -9.376+1.119\ (SI_{BA})$		
d maple	23	46-72	$SI_{RM} = -1.339+0.951\ (SI_{NRO})$	0.72	3.79
red oak	23	50-74	$SI_{NRO} = 18.470+0.760\ (SI_{RM})$	0.72	3.39
			$SI_{RM} = -11.597+1.114\ (SI_{NRO})$		
d maple	33	42-72	$SI_{RM} = 19.203+0.655\ (SI_{BC})$	0.58	4.33
ack cherry	33	42-73	$SI_{BC} = 8.391+0.889\ (SI_{RM})$	0.58	5.05
			$SI_{RM} = 6.478+0.864\ (SI_{BC})$		
d maple	16	46-72	$SI_{RM} = -3.591+0.999\ (SI_{PB})$	0.67	4.75
per birch	16	47-70	$SI_{PB} = 21.976+0.675\ (SI_{RM})$	0.67	3.90
			$SI_{RM} = -16.538+1.215\ (SI_{PB})$		
d maple	8	46-70	$SI_{RM} = -11.216+1.047\ (SI_A)$	0.80	4.01
pens	8	53-75	$SI_A = 21.133+0.766\ (SI_{RM})$	0.80	3.44
			$SI_{RM} = -18.897+1.168\ (SI_A)$		
llow birch	15	51-65	$^1SI_{YB} = 25.611+0.614\ (SI_{AB})$	0.43	2.80
n. beech	15	48-61	$SI_{AB} = 12.459+0.703\ (SI_{YB})$	0.43	3.00
			$SI_{YB} = 7.717+0.948\ (SI_{AB})$		
llow birch	70	40-76	$SI_{YB} = 2.585+0.883\ (SI_B)$	0.78	3.45
n. basswood	70	45-78	$SI_B = 11.951+0.880\ (SI_{YB})$	0.78	3.44
			$SI_{YB} = -4.758+0.998\ (SI_B)$		
llow birch	60	43-76	$SI_{YB} = 11.861+0.746\ (SI_E)$	0.78	2.93
n. elm	60	47-81	$SI_E = 1.371+1.050\ (SI_{YB})$	0.78	3.47
			$SI_{YB} = 5.216+0.850\ (SI_E)$		
llow birch	37	43-76	$SI_{YB} = 12.318+0.715\ (SI_{WA})$	0.68	4.02
hite ash	37	46-84	$SI_{WA} = 9.273+0.956\ (SI_{YB})$	0.68	4.65
			$SI_{YB} = 1.885+0.872\ (SI_{WA})$		
llow birch	20	48-68	$^1SI_{YB} = 22.082+0.585\ (SI_{BA})$	0.61	3.49
ack ash	20	52-78	$^1SI_{BA} = 1.628+1.049\ (SI_{YB})$	0.61	4.68
			$SI_{YB} = 11.436+0.751\ (SI_{BA})$		
llow birch	14	51-68	$SI_{YB} = 3.045+0.849\ (SI_{NRO})$	0.74	2.52
red oak	14	58-72	$SI_{NRO} = 14.390+0.867\ (SI_{YB})$	0.74	2.55
			$SI_{YB} = -6.197+0.992\ (SI_{NRO})$		
llow birch	25	42-71	$SI_{YB} = 18.053+0.674\ (SI_{BC})$	0.61	4.06
ack cherry	25	42-73	$SI_{BC} = 7.385+0.899\ (SI_{YB})$	0.61	4.69
			$SI_{YB} = 6.718+0.863\ (SI_{BC})$		
llow birch	16	42-67	$SI_{YB} = -0.735+0.903\ (SI_{PB})$	0.73	3.79
per birch	16	47-72	$SI_{PB} = 17.342+0.806\ (SI_{YB})$	0.73	3.58
			$SI_{YB} = -10.258+1.058\ (SI_{PB})$		

(Table 2 continued on next page)

(Table 2 continued)

Species comparisons	Paired observations	Site index range	Equations	Coefficient of determination (r^2)	Standard error of estimate
Yellow birch	7	53-76	$SI_{YB} = -5.865+0.934\ (SI_A)$	0.89	3.75
Aspens	7	53-85	$SI_A = 12.670+0.958\ (SI_{YB})$	0.89	3.80
			$SI_{YB} = -9.885+0.994\ (SI_A)$		
Am. basswood	86	48-80	$SI_B = 14.611+0.770\ (SI_E)$	0.70	3.59
Am. elm	86	47-81	$SI_E = 6.421+0.904\ (SI_B)$	0.70	3.89
			$SI_B = 4.856+0.921\ (SI_E)$		
Am. basswood	64	45-80	$SI_B = 18.977+0.689\ (SI_{WA})$	0.70	3.66
White ash	64	44-84	$SI_{WA} = 0.885+1.012\ (SI_B)$	0.70	4.45
			$SI_B = 9.642+0.828\ (SI_{WA})$		
Am. basswood	31	47-78	$SI_B = 13.427+0.797\ (SI_{BA})$	0.63	4.19
Black ash	31	51-78	$SI_{BA} = 13.243+0.789\ (SI_B)$	0.63	4.17
			$SI_B = -0.256+1.010\ (SI_{BA})$		
Am. basswood	29	45-75	$^1SI_B = -5.183+1.065\ (SI_{NRO})$	0.76	3.10
N. red oak	29	50-74	$^1SI_{NRO} = 19.132+0.711\ (SI_B)$	0.76	2.53
			$SI_B = -15.079+1.221\ (SI_{NRO})$		
Am. basswood	15	50-74	$SI_B = 26.527+0.592\ (SI_{BC})$	0.68	3.96
Black cherry	15	49-74	$SI_{BC} = -10.699+1.151\ (SI_B)$	0.68	5.53
			$SI_B = 18.257+0.725\ (SI_{BC})$		
Am. basswood	20	49-74	$SI_B = 9.115+0.825\ (SI_{PB})$	0.67	3.81
Paper birch	20	47-72	$SI_{PB} = 13.238+0.813\ (SI_B)$	0.67	3.78
			$SI_B = -1.913+1.001\ (SI_{PB})$		
Am. basswood	8	45-78	$SI_B = 1.483+0.855\ (SI_A)$	0.72	6.40
Aspens	8	53-85	$SI_A = 17.712+0.847\ (SI_B)$	0.72	6.37
			$SI_B = -8.775+1.004\ (SI_A)$		
Am. elm	51	49-81	$SI_E = 10.769+0.807\ (SI_{WA})$	0.78	3.28
White ash	51	46-84	$^1SI_{WA} = 4.696+0.963\ (SI_E)$	0.78	3.58
			$SI_E = 3.405+0.916\ (SI_{WA})$		
Am. elm	34	45-76	$^1SI_E = 13.004+0.804\ (SI_{BA})$	0.65	4.19
Black ash	34	48-76	$^1SI_{BA} = 11.452+0.814\ (SI_E)$	0.65	4.22
			$SI_E = 0.946+0.993\ (SI_{BA})$		
Am. elm	15	60-75	$SI_E = 7.671+0.903\ (SI_{NRO})$	0.39	3.91
N. red oak	15	59-72	$SI_{NRO} = 35.862+0.429\ (SI_E)$	0.39	2.69
			$SI_E = -24.195+1.402\ (SI_{NRO})$		
Am. elm	16	47-73	$SI_E = 14.628+0.792\ (SI_{BC})$	0.78	3.89
Black cherry	16	42-74	$SI_{BC} = -0.755+0.984\ (SI_E)$	0.78	4.33
			$SI_E = 8.384+0.893\ (SI_{BC})$		
Am. elm	12	49-76	$SI_E = 5.168+0.899\ (SI_{PB})$	0.71	4.49
Paper birch	12	47-72	$SI_{PB} = 14.042+0.784\ (SI_E)$	0.71	4.20
			$SI_E = -5.084+1.066\ (SI_{PB})$		
Am. elm	7	49-81	$SI_E = 5.206+0.816\ (SI_A)$	0.83	4.81
Aspens	7	53-85	$SI_A = 6.593+1.011\ (SI_E)$	0.83	5.35
			$SI_E = -0.214+0.896\ (SI_A)$		
White ash	27	51-76	$SI_{WA} = 3.969+0.981\ (SI_{BA})$	0.75	3.44
Black ash	27	52-76	$SI_{BA} = 12.862+0.766\ (SI_{WA})$	0.75	3.04
			$SI_{WA} = -5.428+1.128\ (SI_{BA})$		

(Table 2 continued on next page)

(Table 2 continued)

Species comparisons	Paired observations	Site index range	Equations	Coefficient of determination (r^2)	Standard error of estimate
White ash	22	44-76	$SI_{WA} = -22.933+1.362\ (SI_{NRO})$	0.77	3.95
Northern red oak	22	50-72	[1]$SI_{NRO} = 27.478+0.566\ (SI_{WA})$	0.77	2.55
			$SI_{WA} = -34.762+1.549\ (SI_{NRO})$		
White ash	9	46-74	$SI_{WA} = -3.853+1.023\ (SI_{PB})$	0.69	5.18
Paper birch	9	47-70	$SI_{PB} = 21.765+0.674\ (SI_{WA})$	0.69	4.21
			$SI_{WA} = -16.344+1.225\ (SI_{PB})$		
White ash	7	44-84	$SI_{WA} = -17.000+1.111\ (SI_{A})$	0.85	5.86
Aspens	7	60-85	$SI_{A} = 23.089+0.767\ (SI_{WA})$	0.85	4.87
			$SI_{WA} = -23.105+1.201\ (SI_{A})$		
Black ash	10	52-76	$SI_{BA} = -9.946+1.154\ (SI_{NRO})$	0.51	4.99
Northern red oak	10	58-72	$SI_{NRO} = 35.708+0.444\ (SI_{BA})$	0.51	3.09
			$SI_{BA} = -37.214+1.579\ (SI_{NRO})$		
Northern red oak	15	50-74	$SI_{NRO} = 0.014+0.997\ (SI_{PB})$	0.63	4.35
Paper birch	15	54-70	$SI_{PB} = 23.734+0.628\ (SI_{NRO})$	0.63	3.46
			$SI_{NRO} = -16.401+1.255\ (SI_{PB})$		
Northern red oak	7	50-74	$SI_{NRO} = 15.208+0.672\ (SI_{A})$	0.59	5.38
Aspens	7	56-80	$SI_{A} = 13.919+0.883\ (SI_{NRO})$	0.59	6.16
			$SI_{NRO} = 1.756+0.872\ (SI_{A})$		
Paper birch	7	47-69	$SI_{PB} = 5.271+0.849\ (SI_{A})$	0.91	2.37
Aspens	7	53-75	$SI_{A} = -0.239+1.077\ (SI_{PB})$	0.91	2.67
			$SI_{PB} = 2.296+0.818\ (SI_{A})$		

[1]Correlations significantly improved (0.05) when a drainage variable is added to the listed linear regressions.

Table 3.—*Northern hardwood groups that combine species that are similar in site index (site-index comparisons were made among these group pairs)*

Species and species groups	SM RM YB	B E BA	WA	BC	NRO PB	A
	number of plots having paired observations					
LOW SITE—American beech	19	[1](4)	(3)	(6)	(2)	(0)
MEDIUM SITE—Sugar maple, red maple yellow birch		140	70	40	50	12
HIGH SITE—a) American basswood, American elm, black ash			68	21	43	10
b) White ash				(6)	26	7
c) Black cherry					8	(1)
d) Northern red oak, paper birch						10
VERY HIGH SITE— Aspens						

[1]Numbers in parentheses are for those group pairs having too few plots for regression analyses.

Table 4.—*Regression equations relating site index between species groups composed of species that are similar in site index (also given are equations that average the trends of the two equations listed for each group pair)*

Species group comparisons	Paired observations	Site index range	Equations	Coefficient of determination (r^2)	Standard error of estimate
	No.	feet			feet
Sugar maple, Red maple, Yellow birch	19	50-62	$SI_{SM,RM,YB} = 29.156+0.540\ (SI_{AB})$	0.49	2.75
Am. beech	19	45-61	$SI_{AB} = 0.947+0.904\ (SI_{SM,RM,YB})$ $^2SI_{SM,RM,YB} = 16.190+0.783\ (SI_{AB})$	0.49	3.57
Sugar maple, Red maple, Yellow birch	140	43-76	$SI_{SM,RM,YB} = 8.024+0.807\ (SI_{B,E,BA})$	0.78	3.08
Am. basswood, Am. elm, Black ash	140	45-80	$SI_{B,E,BA} = 6.004+0.969\ (SI_{SM,RM,YB})$ $^2SI_{SM,RM,YB} = 1.469+0.911\ (SI_{B,E,BA})$	0.78	3.37
Sugar maple, Red maple, Yellow birch	70	44-76	$SI_{SM,RM,YB} = 18.632+0.663\ (SI_{WA})$	0.64	3.77
White ash	70	44-84	$SI_{WA} = 4.615+1.033\ (SI_{SM,RM,YB})$ $^2SI_{SM,RM,YB} = 7.913+0.783\ (SI_{WA})$	0.64	4.86
Sugar maple, Red maple, Yellow birch	40	42-72	$SI_{SM,RM,YB} = 18.009+0.675\ (SI_{BC})$	0.67	3.74
Black cherry	40	42-74	$SI_{BC} = 2.109+0.998\ (SI_{SM,RM,YB})$ $^2SI_{SM,RM,YB} = 8.697+ .826\ (SI_{BC})$	0.67	4.56
Sugar maple, Red maple, Yellow birch	50	44-72	$SI_{SM,RM,YB} = 0.831+0.905\ (SI_{NRO,PB})$	0.68	3.83
N. red oak, Paper birch	50	47-72	$SI_{NRO,PB} = 19.553+0.748\ (SI_{SM,RM,YB})$ $^2SI_{SM,RM,YB} = -11.199+1.098\ (SI_{NRO,PB})$	0.68	3.48
Sugar maple, Red maple, Yellow birch	12	44-76	$SI_{SM,RM,YB} = -0.847+0.857\ (SI_{A})$	0.76	4.80
Aspens	12	53-85	$SI_{A} = 16.972+0.886\ (SI_{SM,RM,YB})$ $^2SI_{SM,RM,YB} = -9.218+0.981\ (SI_{A})$	0.76	4.88
Am. basswood, Am. elm, Black ash	68	45-80	$SI_{B,E,BA} = 15.727+0.733\ (SI_{WA})$	0.79	3.01
White ash	68	44-84	$SI_{WA} = -3.361+1.084\ (SI_{B,E,BA})$ $SI_{B,E,BA} = 9.608+0.825\ (SI_{WA})$	0.79	3.66
Am. basswood, Am. elm, Black ash	21	48-74	$SI_{B,E,BA} = 21.549+0.681\ (SI_{BC})$	0.70	3.93
Black cherry	21	42-74	$SI_{BC} = -3.436+1.025\ (SI_{B,E,BA})$ $SI_{B,E,BA} = 13.407+0.813\ (SI_{BC})$	0.70	4.82

(Table 4 continued on next page)

(Table 4 continued)

Species group comparisons	Paired observations	Site index range	Equations	Coefficient of determination(r^2)	Standard error of estimate
m. basswood, Am. elm, Black ash	43	45-75	$SI_{B,E,BA} = 0.610+0.982\ (SI_{NRO,PB})$	0.74	3.48
red oak, Paper birch	43	47-72	$SI_{NRO,PB} = 15.579+0.757\ (SI_{B,E,BA})$ $SI_{B,E,BA} = -9.013+1.136\ (SI_{NRO,PB})$	0.74	3.05
m. basswood, Am. elm, Black ash	10	45-80	$^1SI_{B,E,BA} = -2.907+0.923\ (SI_A)$	0.76	5.61
spens	10	53-85	$SI_A = 18.510+0.825\ (SI_{B,E,BA})$ $SI_{B,E,BA} = -11.886+1.056\ (SI_A)$	0.76	5.30
hite ash	26	44-77	$^1SI_{WA} = -20.429+1.330\ (SI_{NRO,PB})$	0.75	4.47
red oak, Paper birch	26	47-72	$SI_{NRO,PB} = 27.222+0.564\ (SI_{WA})$ $^1SI_{WA} = -33.250+1.534\ (SI_{NRO,PB})$	0.75	2.91
hite ash	7	44-84	$SI_{WA} = -17.000+1.111\ (SI_A)$	0.85	5.86
spens	7	60-85	$SI_A = 23.089+0.767\ (SI_{WA})$ $SI_{WA} = -23.105+1.201\ (SI_A)$	0.85	4.87
ack cherry	8	49-73	$^1SI_{BC} = 4.211+0.927\ (SI_{NRO,PB})$	0.77	4.16
red oak, Paper birch	8	49-71	$SI_{NRO,PB} = 11.568+0.826\ (SI_{BC})$ $^1SI_{BC} = -4.098+1.056\ (SI_{NRO,PB})$	0.77	3.93
red oak, Paper birch	10	47-71	$SI_{NRO,PB} = 14.394+0.684\ (SI_A)$	0.71	4.07
spens	10	53-80	$SI_A = 4.113+1.034\ (SI_{NRO,PB})$ $SI_{NRO,PB} = 5.629+0.819\ (SI_A)$	0.71	5.00

orrelations significantly improved (0.05) when a drainage variable is added to the listed linear regressions.
verage equations used for calculating the general species site index comparison graph (fig. 1).

^{2}) of the total site index variation between species pairs (table 2) or group pairs (table 4). Such esults represent an acceptable level of precision, owever, efforts were made to further reduce data ariation and thereby make the regression equaons even more precise. Soil profile descriptions r each site plot were used to classify soil drainage ased on depth to mottling and on the amount and rightness of mottling (USDA Soil Conservation ervice 1975). A comparison between residuals difference between actual and predicted site inex) and soil drainage revealed that a portion of he remaining variation of the regressions was ssociated with soil drainage.

A linear transformation of the soil drainage classification for each plot[2] was added to all regressions between species pairs (table 2) and group pairs (table 4). An additional quadratic transformation of the drainage variable also was added to test for curvilinear relations. Adding this drainage variable significantly improved the precision

[2]Drainage classes (USDA, Soil Conservation Service 1975) are: poorly drained = 1; somewhat poorly drained = 2; moderately well drained = 3; well-drained = 4; and excessively drained = 5. Drainage classes were estimated to the nearest 0.1 to allow for gradations between classes (fig. 3).

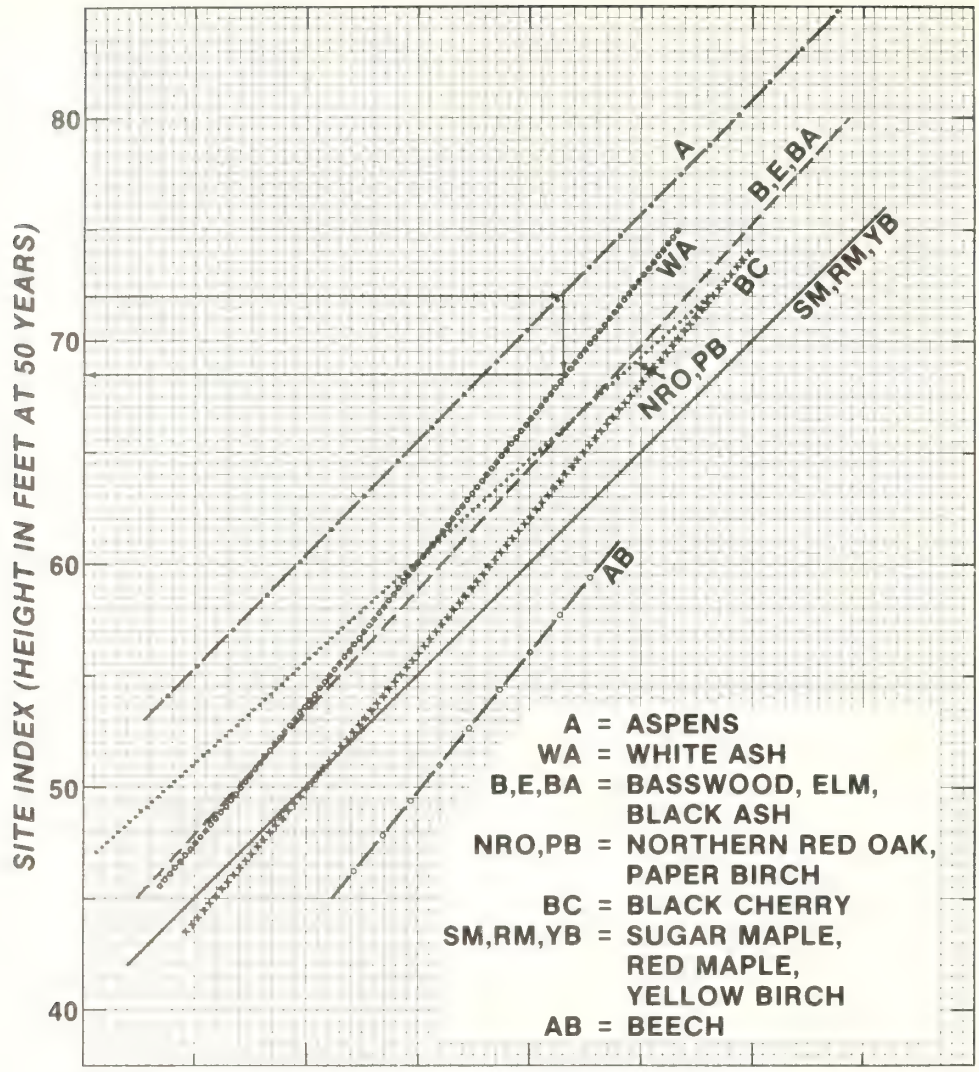


Figure 1.—*Site index comparison graphs for northern hardwood species in northern Wisconsin and Upper Michigan. These graphs can be used to estimate site index for species absent from forest stands by using site-index estimates of tree species that are present. For example, suppose you would like to estimate the site index for white ash in a certain stand, but there are no white ash trees present. However, there are suitable aspen trees present, and their average height and age measurements indicate that their site index is 72 (Carmean 1978). So, on the graph begin at 72 on the site-index scale and read right to the aspen line, then read straight down to the white ash line. Now read left to the site-index scale where estimated site index for white ash is found to be 68.5. The reverse of this procedure also can be used; for example, site index 68.5 for white ash indicates a site index of 72 for aspen.*

of the regression equations for 14 of the species and group pairs (table 5). The linear transformation was adequate for expressing drainage relations in all regressions, except for the American elm-black ash species pair. For this species pair the quadratic transformation resulted in a significant (at the 5 percent level) improvement in precision in addition to the precision gained from using only the linear transformation.

Graphically derived average regression equations were also calculated for the 14 species or

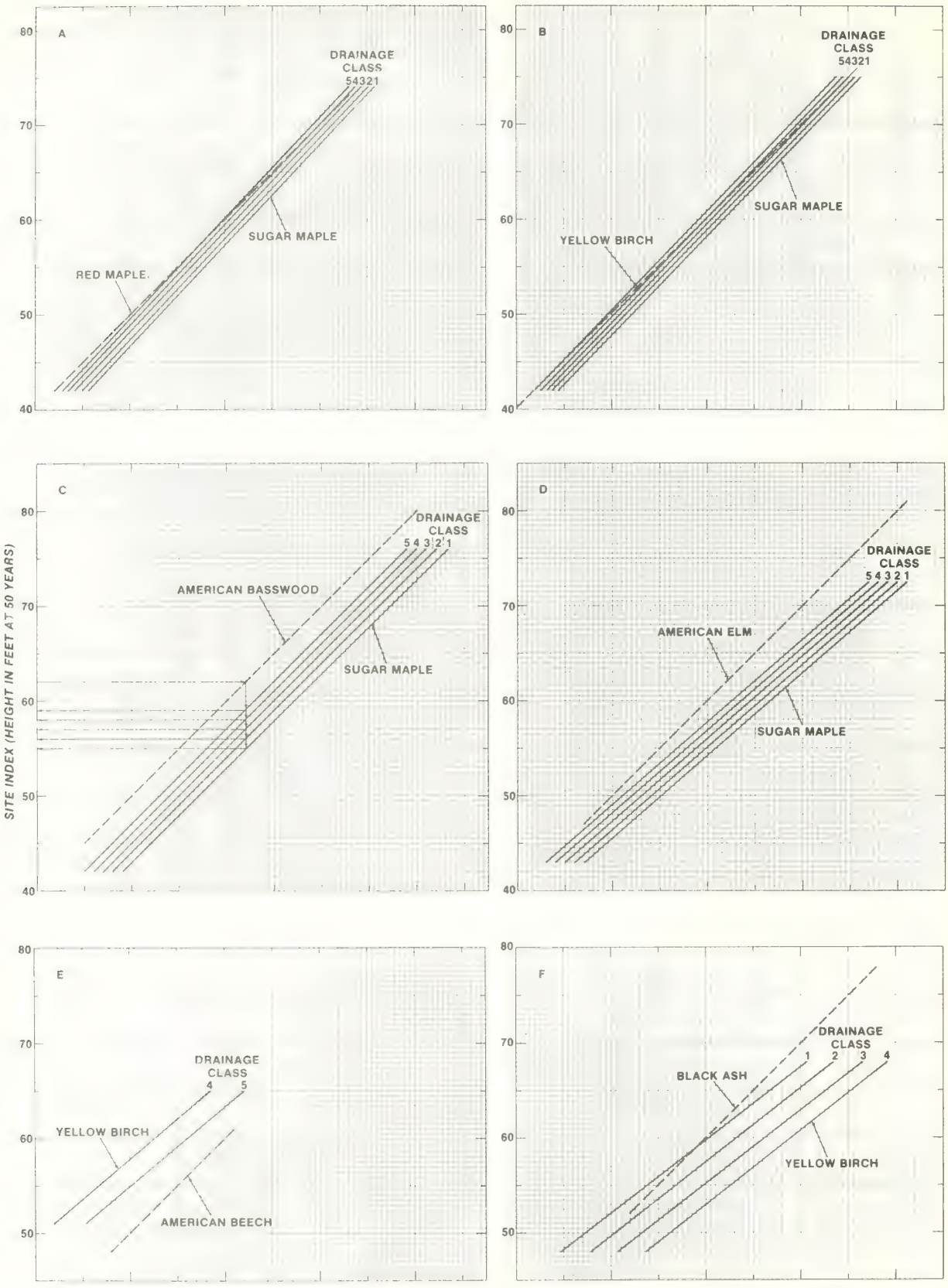
able 5.—*Regression equations relating site index between species and group pairs when drainage[1] is included as a significant (0.05) variable (also given are equations that average the trends of the two equations listed for each species or group pair)*

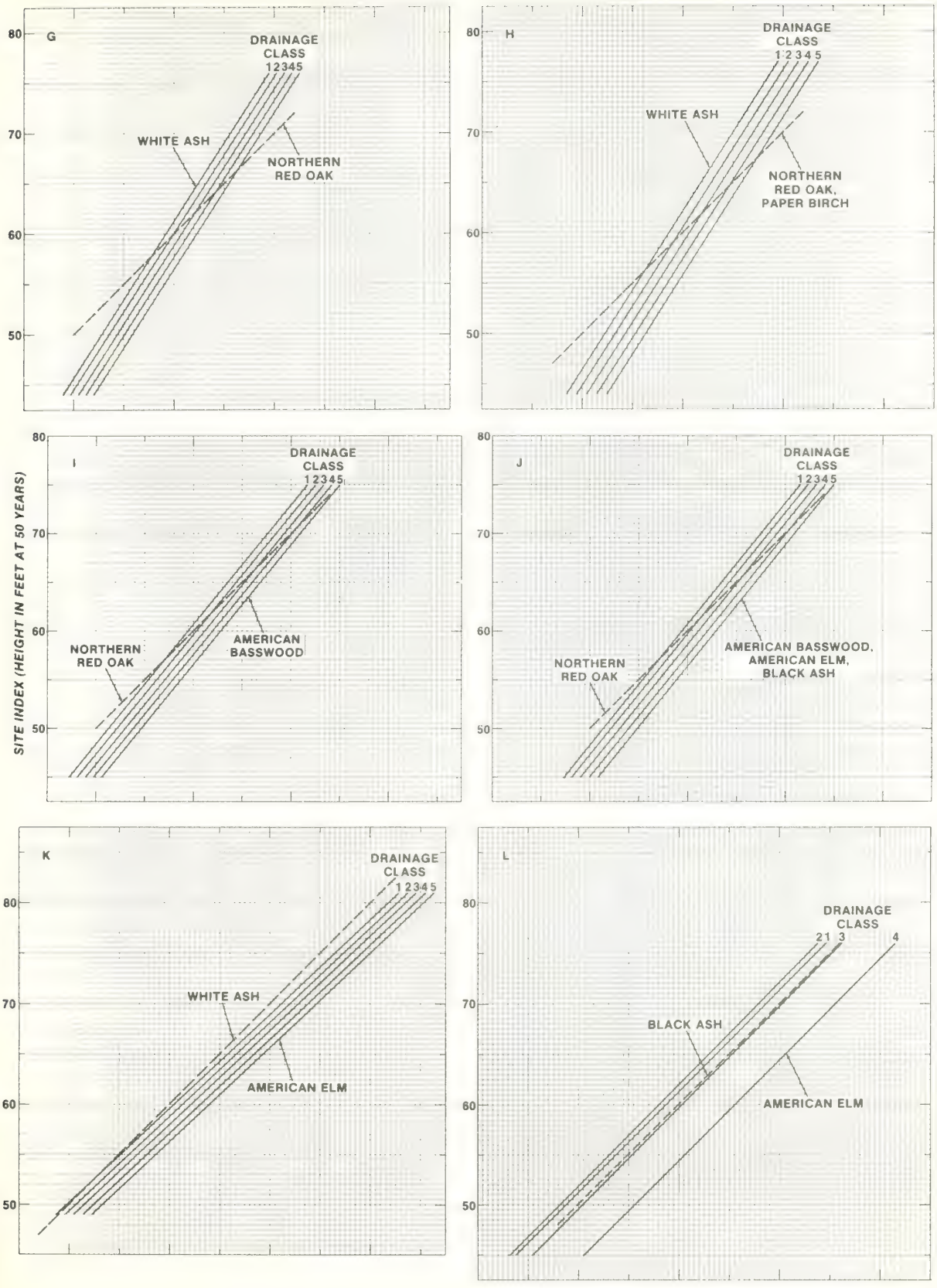
pecies omparisons	Paired observations	Equations	Coefficient of determination (r^2)[2]	Standard error of estimate[2]
				feet
ugar maple	89	$SI_{SM} = -0.204+0.948\ (SI_{RM})+0.700\ (dr)$	0.81(0.79)	3.04(3.14)
ed maple	89	$SI_{RM} = 11.933+0.852\ (SI_{SM})-0.730\ (dr)$	0.81(0.79)	2.88(3.00)
		$SI_{SM} = -6.778+1.055\ (SI_{RM})+0.715\ (dr)$		
ugar maple	109	$SI_{SM} = 4.016+0.892\ (SI_{YB})+0.661\ (dr)$	0.74(0.73)	3.60(3.66)
ellow birch	109	$SI_{YB} = 12.389+0.829\ (SI_{SM})-0.663\ (dr)$	0.74(0.73)	3.47(3.53)
		$SI_{SM} = -4.775+1.037\ (SI_{YB})+0.662\ (dr)$		
ugar maple	109	$SI_{SM} = 2.136+0.839\ (SI_{B})+1.141\ (dr)$	0.71(0.68)	3.61(3.77)
n. basswood	109	$SI_{B} = 17.229+0.842\ (SI_{SM})-1.042\ (dr)$	0.71(0.68)	3.62(3.74)
		$SI_{SM} = -8.299+1.000\ (SI_{B})+1.092\ (dr)$		
ugar maple	94	$SI_{SM} = 8.466+0.750\ (SI_{E})+1.028\ (dr)$	0.74(0.71)	3.37(3.52)
n. elm	94	$SI_{E} = 9.334+0.957\ (SI_{SM})-0.778\ (dr)$	0.72(0.71)	3.81(3.87)
		$SI_{SM} = 0.820+0.874\ (SI_{E})+0.903\ (dr)$		
ellow birch	15	$SI_{YB} = 38.764+0.630\ (SI_{AB})-3.060\ (dr)$	0.65(0.43)	2.29(2.80)
n. beech	15	[3] $SI_{AB} = -11.994+0.897\ (SI_{YB})+2.858\ (dr)$	0.57(0.43)	2.73(3.00)
		$SI_{YB} = 27.645+0.842\ (SI_{AB})-2.959\ (dr)$		
ellow birch	20	$SI_{YB} = 22.159+0.656\ (SI_{BA})-1.792\ (dr)$	0.70(0.61)	3.16(3.49)
ack ash	20	$SI_{BA} = -6.289+1.069\ (SI_{YB})+2.618\ (dr)$	0.73(0.61)	4.03(4.68)
		$SI_{YB} = 14.950+0.781\ (SI_{BA})-2.205\ (dr)$		
n. basswood	29	$SI_{B} = -4.459+1.107\ (SI_{NRO})-1.166\ (dr)$	0.80(0.76)	2.84(3.10)
red oak	29	$SI_{NRO} = 15.415+0.725\ (SI_{B})+0.980\ (dr)$	0.81(0.76)	2.30(2.53)
		$SI_{B} = -12.118+1.232\ (SI_{NRO})-1.703\ (dr)$		
n. elm[3]	51	$SI_{E} = 10.869+0.833\ (SI_{WA})-0.704\ (dr)$	0.79(0.78)	3.22(3.28)
hite ash	51	$SI_{WA} = 3.201+0.946\ (SI_{E})+1.003\ (dr)$	0.79(0.78)	3.43(3.58)
		$SI_{E} = 4.066+0.940\ (SI_{WA})-0.854\ (dr)$		
n. elm	34	$SI_{E} = 3.775+0.888\ (SI_{BA})+6.190\ (dr)-1.671\ (dr^2)$	0.78(0.65)	3.46(4.19)
ack ash	34	$SI_{BA} = 10.381+0.852\ (SI_{E})-4.166\ (dr)+1.321\ (dr^2)$	0.79(0.65)	3.39(4.22)
		$SI_{E} = -2.945+1.010\ (SI_{BA})+5.178\ (dr)-1.496\ (dr^2)$		
hite ash	22	$SI_{WA} = -22.374+1.414\ (SI_{NRO})-1.419\ (dr)$	0.81(0.77)	3.70(3.96)
red oak	22	$SI_{NRO} = 24.477+0.573\ (SI_{WA})+0.956\ (dr)$	0.82(0.77)	2.35(2.55)
		$SI_{WA} = -31.350+1.561\ (SI_{NRO})-1.188\ (dr)$		
n. basswood, Am. elm, Black ash	30	$SI_{B,E,BA} = -3.801+1.093\ (SI_{NR0})-1.110\ (dr)$	0.78(0.74)	2.99(3.20)
red oak	30	$SI_{NRO} = 16.410+0.711\ (SI_{B,E,BA})+0.955\ (dr)$	0.78(0.74)	2.41(2.62)
		$SI_{B,E,BA} = -12.790+1.240\ (SI_{NRO})-1.032\ (dr)$		
n. basswood, Am. elm, Black ash	10	$SI_{B,E,BA} = -0.054+0.737\ (SI_{A})+3.804\ (dr)$	0.91(0.76)	3.56(5.61)
spens	10	$SI_{A} = 10.217+1.123\ (SI_{B,E,BA})-3.681\ (dr)$	0.86(0.76)	4.40(5.30)
		$SI_{B,E,BA} = -4.009+0.806\ (SI_{A})+3.742\ (dr)$		
hite ash	26	$SI_{WA} = -21.764+1.422\ (SI_{NRO,PB})-1.775\ (dr)$	0.80(0.75)	4.11(4.47)
red oak, Paper birch	26	$SI_{NRO,PB} = 24.219+0.561\ (SI_{WA})+1.270\ (dr)$	0.81(0.75)	2.58(2.91)
		$SI_{WA} = -30.802+1.572\ (SI_{NRO,PB})-1.522\ (dr)$		
ack cherry	8	$SI_{BC} = -10.115+0.995\ (SI_{NRO,PB})+2.831\ (dr)$	0.97(0.77)	1.69(4.16)
red oak, Paper birch	8	$SI_{NRO,PB} = 12.211+0.969\ (SI_{BC})-2.774\ (dr)$	0.96(0.77)	1.67(3.93)
		$SI_{BC} = -10.639+1.004\ (SI_{NRO,PB})+2.802\ (dr)$		

elative drainage classes are: 1 = poorly drained; 2 = somewhat poorly drained; 3 = moderately well drained; 4 = well drained; 5 = somewhat excessively drained SDA, Soil Conservation Service 1975).

umbers in parentheses are the coefficients of determination, and the standard errors of estimate for regression equations without drainage variable (table 2)

oefficient for the drainage variable not significant because probability of error exceeds 5 percent.


A
DRAINAGE CLASS 54321
SUGAR MAPLE
RED MAPLE
B
DRAINAGE CLASS 54321
SUGAR MAPLE
YELLOW BIRCH
C
DRAINAGE CLASS 5 4 3 2 1
AMERICAN BASSWOOD
SUGAR MAPLE
D
DRAINAGE CLASS 54321
AMERICAN ELM
SUGAR MAPLE
E
DRAINAGE CLASS 4 5
YELLOW BIRCH
AMERICAN BEECH
F
DRAINAGE CLASS 1 2 3 4
BLACK ASH
YELLOW BIRCH
SITE INDEX (HEIGHT IN FEET AT 50 YEARS)
80
70
60
50
40


G
DRAINAGE CLASS 12345
WHITE ASH
NORTHERN RED OAK
H
DRAINAGE CLASS 12345
WHITE ASH
NORTHERN RED OAK, PAPER BIRCH
I
DRAINAGE CLASS 12345
NORTHERN RED OAK
AMERICAN BASSWOOD
J
DRAINAGE CLASS 12345
NORTHERN RED OAK
AMERICAN BASSWOOD, AMERICAN ELM, BLACK ASH
K
DRAINAGE CLASS 12345
WHITE ASH
AMERICAN ELM
L
DRAINAGE CLASS 21 3 4
BLACK ASH
AMERICAN ELM
SITE INDEX (HEIGHT IN FEET AT 50 YEARS)
80
70
60
50

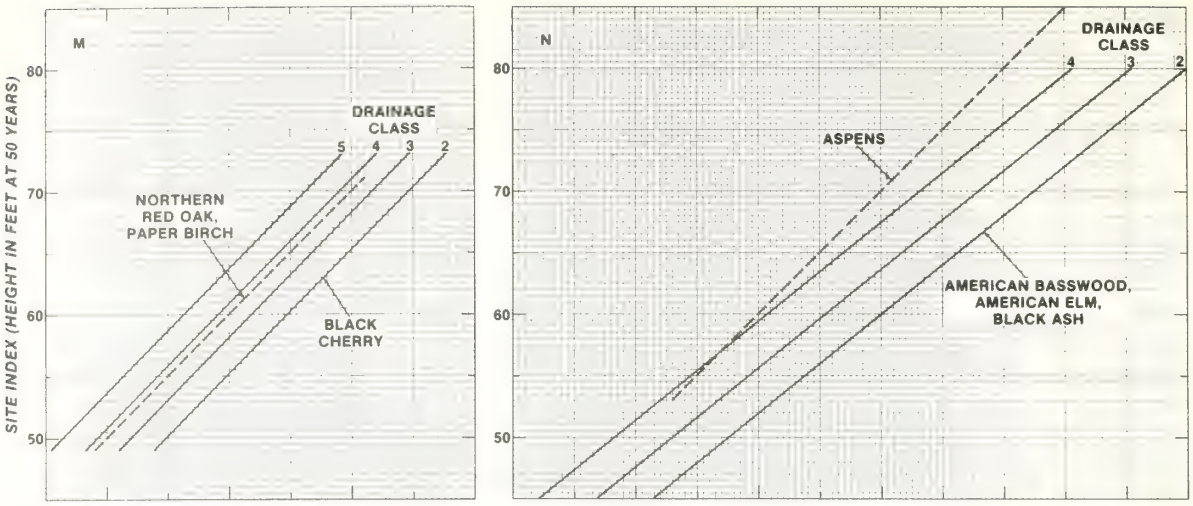


Figure 2.—*Site index comparison graphs for northern hardwood species whose site index relations differ depending upon soil drainage. For example, suppose you would like to estimate site index for sugar maple in a certain stand, but there are no sugar maple trees present. However, there are suitable American basswood trees present, and their average height and age measurements indicate that their site index is 62 (Carmean 1978). Find the graph that compares the two species you are working with—graph C. On the graph begin at 62 on the site-index scale and read right to the American basswood line, then read straight down to the sugar maple lines for various classes of soil drainage. Now read left to the site-index scale where site index for the various drainage classes can be found. For basswood site index 62 sugar maple site index is estimated to be 59, 58, 57, 56, and 55 for soils that are somewhat excessively drained (class 5), well drained (class 4), moderately well drained (class 3), somewhat poorly drained (class 2), and poorly drained (class 1), respectively. The reverse of this procedure also can be used to estimate site index for basswood if sugar maple site index and drainage class are known.*

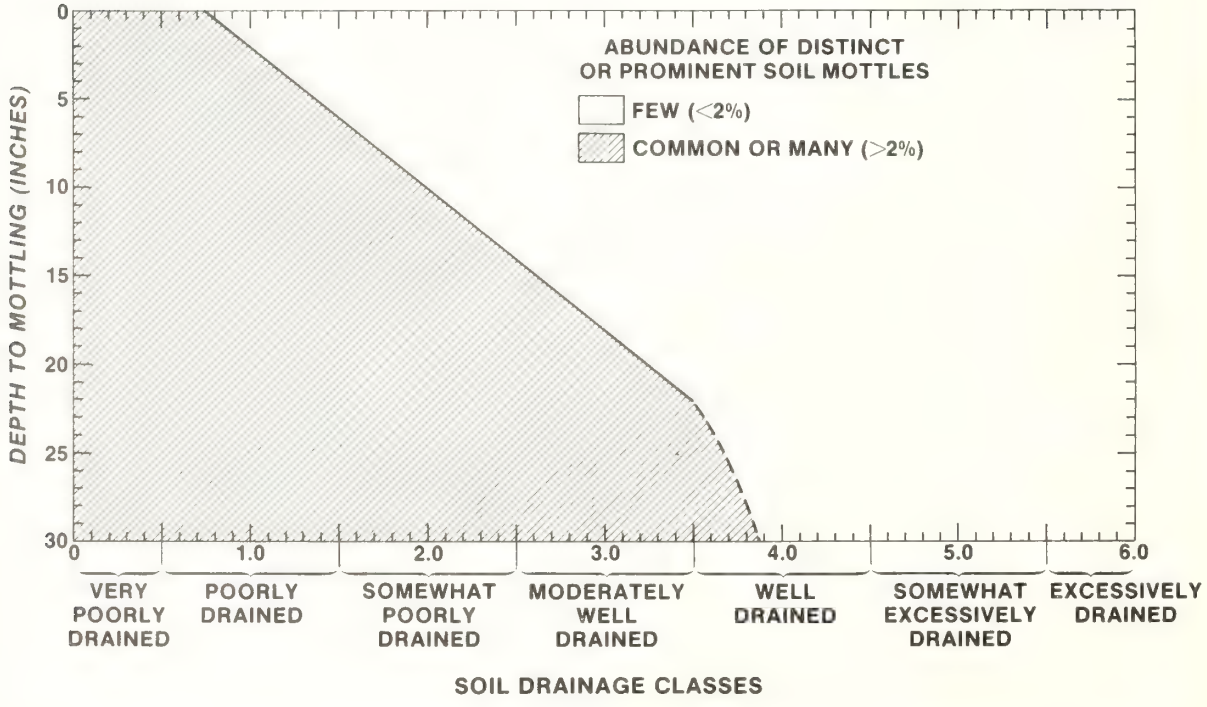


Figure 3.–Soil drainage classes can be estimated from depth to a soil horizon having common or many mottles that are distinct or prominent when contrasted to the soil matrix (USDA Soil Conservation Service 1975).

up pairs where site relations were found to be nificantly related to soil drainage (table 5). ese average equations were used to plot graphs t show site relations between species or group rs for different soil drainage classes (fig. 2). ch graph is restricted to the observed range of e index and drainage observed on the site plots. re precise estimates of site index can be ob- ned with these comparison graphs that include inage than can be obtained with the general e index comparison graph (fig. 1). And the most cise site index estimates of all can be obtained ng either of the two computed regression equa- ns (table 5).

For many species combinations the site changes ociated with soil drainage are minor even ugh they are statistically significant. For ex- ple, when the drainage variable is added to the ressions for the sugar maple-red maple and the gar maple-yellow birch pairs, the site index esti- tes are statistically improved (table 5), but the gnitude of the site index changes are small s. 2A and 2B)—site index changes less than 1 t for each unit (1.0) change in drainage. In con- st, adding the drainage variable for species rs such as yellow birch-American beech and low birch-black ash, greatly improves statisti- precision (table 5) and also results in large site ex changes (figs. 2E and 2F). For example, for yellow birch-American beech species pair site ex changes about 3.0 feet for each unit (1.0) nge in drainage. Other pairs such as American -black ash, and black cherry-(red oak and pa- birch) also appear to have large site index nges associated with drainage (figs. 2L and). However, many of these species or group rs are based on few plots and the standard er- s for the drainage coefficients are large, thus we not place much confidence in the actual magni- e of the estimated site changes associated with inage.

DISCUSSION

This study shows that species found in northern rdwood stands have large differences in site in- x. Differences in site index may average as ch as 15 feet between aspen and American ch when they occur on small 1/5-acre plots. On od sites the site index for white ash may average r more feet higher than site indices for sugar ple, red maple, and yellow birch. Northern hardwood species can be placed into four general site index groups: (a) *Very high site*-species include quaking and bigtooth aspens. These species have rapid early height growth and at 50 years of age will be taller than all other species, (b) *High site*-species include 7 intolerant species - white ash, American basswood, American elm, black ash, black cherry, northern red oak, and paper birch. Differences in site index occur among these species depending upon level of site quality. On good sites white ash has site indices exceeding those of the other high site species; on poor sites northern red oak and paper birch have the highest site indices. Black cherry has high site indices on good sites but relatively low site indices on poor sites, (c) *Medium site*-species include sugar maple, red maple, and yellow birch, (d) *Low site*-species is American beech, which has the lowest site indices at all levels of site quality.

These site relations frequently differ depending upon soil drainage; species that have similar site indices on well-drained soils often have dissimilar site indices on less well-drained soils. For example, on well-drained soils the site indices for sugar maple, red maple, and yellow birch are similar. But on less well-drained soils sugar maple site index is lower than red maple and yellow birch site index (figs. 2A and 2B). Comparisons between sugar maple, American basswood, and American elm (figs. 2C and 2D) reveal similar relations. On well-drained soils basswood and elm may have site indices 3 or more feet higher than sugar maple, but on poorly drained soils site indices may be as much as 7 feet higher than for sugar maple.

On well-drained soils black ash grows faster than do many associated trees. For example, black ash and yellow birch have similar site indices on poorly drained soils, but on well-drained soils black ash has site indices averaging 7 or more feet greater than yellow birch (fig. 2F). Similar relations occur when white ash (fig. 2K) and black ash (fig. 2L) site indices are compared to American elm site index. Site indices for these three species are similar on poorly drained soils, but on well-drained soils site indices for the ashes are at least 5 feet higher than for elm. Site indices for white ash, northern red oak, and paper birch also differ for different levels of site quality (figs. 2G and 2H). On poor sites white ash has much lower site index and differences become greater as drainage improves. In contrast, on good sites white ash has much higher site index than red oak and paper birch and

these differences become greater as drainage becomes poorer. Somewhat similar but less pronounced relations also occur when northern red oak site index is compared to site indices for American basswood, American elm, and black ash (figs. 2I and 2J).

Other site index comparison studies for northern hardwood species have been made in Vermont (Curtis and Post 1962), and included sugar maple, yellow birch, white ash, and paper birch. A study in northern Minnesota (Carmean and Vasilevsky 1971) included site comparisons for American basswood, northern red oak, paper birch, and quaking aspen. Results from these two studies are similar to this study for northern Wisconsin and Upper Michigan except for paper birch. In Vermont paper birch apparantly had rather low site indices on poor sites, but in the present study paper birch had higher site indices on poor sites. In northern Minnesota paper birch had site indices 3 to 5 feet higher than for northern red oak, but in this study paper birch and red oak had similar site indices at all levels of site quality.

Most of the regression equations developed in this study have exceptionally high r^2 values. The major reason for this good precision is that a large number of site trees were measured on many carefully selected even-aged plots, and that all site index values are based on detailed stem analyses from each site tree. Stem analysis permits a direct and more accurate observation of site index in contrast to estimating site index using only total height and age measurements in conjunction with site index curves.

Site index comparisons among alternative tree species are a necessary first step in selecting the most desirable tree species for a given site. During selection we should remember that site index comparisons are merely comparisons of tree height at index age and that height growth before and after index age should also be considered. Aspens grow rapidly in early years and thus are taller than sugar maple and other northern hardwoods at 50 years (site index age). But after 50 years aspen height growth slows while most hardwoods maintain more rapid height growth until older years. Rapid early height and volume growth of aspen is a desirable feature for short rotation pulp and fiber products. But valued hardwoods might be preferable to aspen on good sites because better growth in later years would be an advantage in growing quality saw logs and veneer logs.

Site index camparisons enable forest managers to also compare the volume and value of wood produced by different species on different sites. On good sites species such as yellow birch, black cherry, and the ashes might be preferable to aspen even though they do not grow as rapidly in height and volume as do aspens. These species might be preferred because comparisons with aspen on a value basis may show that even though they produce less volume they have the potential for producing high quality veneer and saw logs and thus may produce more value return than may be gained by aspen. White ash is a particularly desirable tree because it combines rapid early height and volume growth with great value for quality saw log and veneer logs. American beech combines slow early height and volume growth with wood products that are relatively low in value.

HOW TO USE THE SITE INDEX COMPARISON GRAPHS AND EQUATIONS

1. Select the stand or plot for which site index estimates are needed. Measure total height and total age of several dominant and codominant trees of the tree species present that are suitable for estimating site index. Use site index curves (Carmean 1978) to estimate site index for these species.

2. Classify soil drainage using standard soil profile descriptions based on depth to mottling and on abundance and contrast of mottles (USDA Soil Conservation Service 1975) (fig. 3).

Abundance of mottles: few = < 2%; common = 2-20%; many = > 20% of soil matrix.

Contrast of mottles: faint = mottles and matrix closely related in hue and chroma; distinct = mottles and matrix contrast by 1-2 units in hue and by several units in chroma and value; prominent = mottles and matrix contrast by several units in hue, chroma, and value.

Northern hardwood stands rarely occur in "very poorly drained" swampy areas, or on "excessively drained" sandy and gravelly soils with little profile development. But northern hardwood stands

nonly occur on "well drained" glacial till soils lack large amounts of mottles; stands also nonly occur on "somewhat excessively ned" glacial outwashed sandy soils that have developed soil profiles.

List the absent tree species for which site x estimates are desired. Then list paired com-tions between the species that are present and bsent species for which you desire site index nates.

Determine if the tree species you wish site x estimates for are among the 14 paired com-tions in which soil drainage is important for nating site index (fig. 2 and table 5). If drain-s a significant factor, estimate site index for bsent species using the individual site index arison graphs that include drainage as a fac-or estimating site index. Even more precise ndex estimates are possible using the com-d equations that express relations between ndex and soil drainage (table 5). If drainage is significant factor in estimating site index, or u do not have the soil profile descriptions ed to classify soil drainage, use the general ndex comparison graph (fig. 1) to estimate ndex of the absent species based on site index ecies present. More precise site index esti-s are possible using the computed equations ther the group pairs (table 4), or the species (table 2).

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Potential for energy recovery from humid air streams

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POTENTIAL FOR ENERGY RECOVERY FROM HUMID AIR STREAMS

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A prime consideration of the forest products industry is to reduce energy consumption. Since the drying of wood accounts for over half the energy consumed in primary manufacturing of forest products, energy saved here could be substantial. Especially promising for recovery is the energy in the humid air exhausted from dryer vents (Rosen 1978, Corder and Turner 1978). Currently, industry usually exhausts humid air from veneer and lumber dryers directly to the atmosphere without any attempt at recovery.

The practice of recovering heat from exhaust gas streams is not new to the forest products industry. Stack gases from boilers have been passed through "economizers" to preheat the air to the boilers (Woodruff and Lammers 1967). The difference between boiler stack gases and dryer vent streams is that the dryer vent streams contain considerable water vapor; thus, the heat of condensation of the water vapor as well as the heat evolved from a temperature change can be transferred to another stream.

The potential energy available for recovery needs to be determined before the modifications to existing equipment can be justified. The purpose of this paper is to calculate the energy recoverable from vent air streams over a range of dry bulb temperatures, T_{db}, from 200 to 400°F and wet bulb temperatures, T_{wb}, from 100 to 212°F (for notation, see Appendix). The vent air is assumed to pass through a recovery (regenerative) heat exchanger where heat is transferred to another liquid or gas stream for use elsewhere in the processing plant. Vent air temperature drops across the recovery heater, ΔT_r range from 100 to 300°F.

BASIS FOR CALCULATIONS

Assume that the vent air from the dryer goes into the regenerative heat exchanger at a dry bulb temperature T_1 and a humidity W_1 and leaves at T_2 and W_2 (fig. 1). Total pressure remains constant at 1 atmosphere. An enthalpy (heat content) balance on the humid vent air yields:

enthalpy change of vent air stream, Δh_r = sensible heat release of air + sensible and latent heat release of steam

Sensible heat is that evolved as a result of temperature change. Latent heat is that evolved as the result of vapor condensation.

The following discontinuous function, based on one pound of dry air, was used to calculate Δh_r:

Only sensible heat removed ($W_1 \leq W_s$)

$$\Delta h_r = \frac{h_{air} + W_1 \Delta h_{st}}{W_1} \qquad (1)$$

Sensible and latent heat removed ($W_1 > W_s$)

$$\Delta h_r = \frac{\Delta h_{air} + W_s \Delta h_{st} + (W_1 - W_s) \Delta h_{cond}}{W_1} \qquad (2)$$

where, Δh_{air}, Δh_{st}, Δh_{cond} are the changes in enthalpy of air, steam, and condensate, respectively, based on Btu/lb of air or water.

W_1 is the inlet humidity of the vent air stream in lb water/lb dry air (in Equation 1, $W_1 = W_2$).

W_s is the saturation humidity at T_2 in lb water/lb dry air (in Equation 2, $W_s = W_2$).

The decrease in enthalpy of the vent stream must equal the increase in enthalpy of the heated stream, thus Δh_r is also the recoverable energy from the heat exchanger. The units of Δh_r, Btu/lb water vapor, were thought to be those most useful for calculating total potential energy savings from a dryer vent stream (see examples in the Appendix).

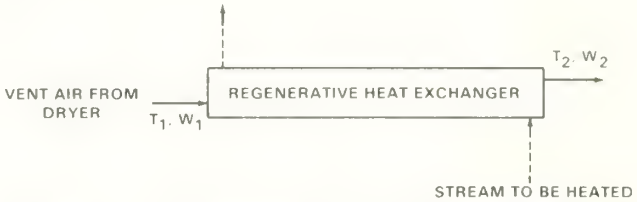

Figure 1.—*Flow streams through regenerative heat exchanger.*

DEVELOPMENT OF RECOVERABLE ENERGY TABLES

Calculations of Δh_r were made for Equations 1 and 2 over a range of T_1 (or T_{db}) from 200 to 400°F, of T_{wb} from 100 to 212°F, and ΔT_r from 100 to 300°F (tables 1-11, p. 5-9). Humidity is usually determined indirectly from readings of wet and dry bulb temperatures. Conversion from values of T_{db} and T_{wb} to humidity can be made from figures 2 and 3.

Further explanation of the terms in Equations 1 and 2, as well as the references from which specific values of these terms were taken, are given below:

Δh_{air} is the enthalpy of dry air at T_1 less the enthalpy change of dry air at T_2 (Zimmerman and Lavine 1964).

Δh_{st} is the enthalpy of water vapor at T_1 less the enthalpy of water vapor at T_2 (Zimmerman and Lavine 1964).

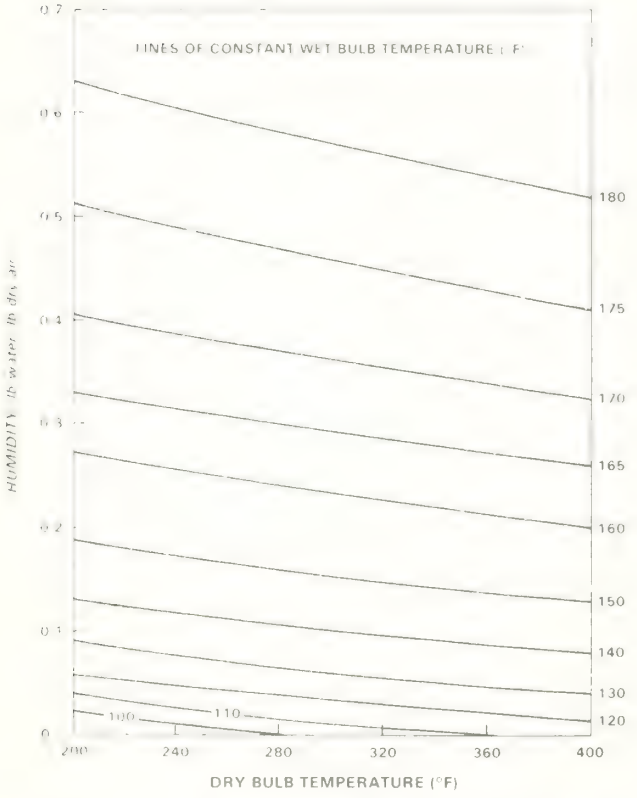

Figure 2.—*High temperature psychrometric chart, wet bulb temperature lines at low humidity range (100 to 180 °F T_{wb}) (Anonymous 1976).*

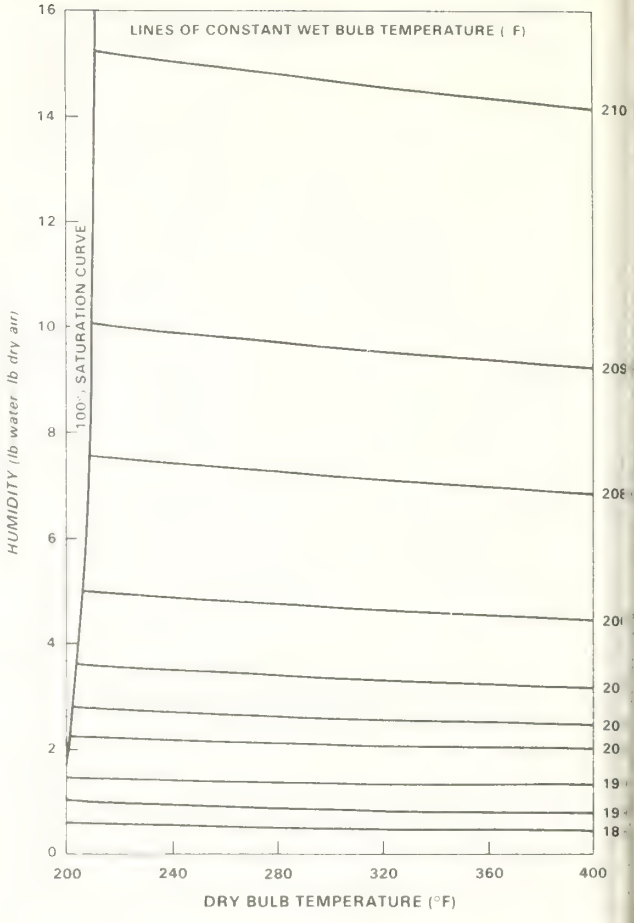

Figure 3.—*High temperature psychrometric chart, wet bulb temperature lines at high humidity range (180 to 210 °F T_{wb}) (Anonymous 1976 Krischer 1956).*

Δh_{cond} is the enthalpy of water vapor at T_1 less the enthalpy of liquid water at T_2 (Zimmerman and Lavine 1964).

W_s (Zimmerman and Lavine 1964).

W_1 (figs. 2 and 3).

Two limitations were placed on the calculations for the recoverable energy tables: first, calculations were not made for $W_1 < 0.001$, since values so small are not of practical value, and second, no calculations were made for $T_2 < 70$°F, since most streams in a wood processing plant are higher than this temperature.

The dotted line in the tables represents the transition from where only sensible heat is recovered to where sensible and latent heat are recovered. All values above the dotted line include only sensible heat recovery. The values at the bottom of each

table specifically give Δh_r and T_{wb} at the transition (T^*_{wb}, in parentheses). At this point, T_2 equals the dew point of the vent air stream.

Before examining the implications of the recoverable energy tables, two important concepts are discussed: (1) the difference between the wet bulb temperature and dew point temperature of a humid air stream, and (2) the importance of heat of condensation in energy recovery.

The *wet bulb temperature* is the equilibrium temperature obtained by a small reservoir of water in contact with a large amount of air flowing past it, such that the latent heat carried away by the evaporation of water into the gas is equal to the sensible heat transferred from the gas to the liquid (Bennett and Meyers 1962). The *dew point temperature* (T_{dp}) is the temperature at which a given sample of moist air becomes saturated as it is cooled at constant pressure and humidity. For a given T_{db}, T_{wb}'s are higher than T_{dp}'s but approach each other as T_{wb} increases (fig. 4).

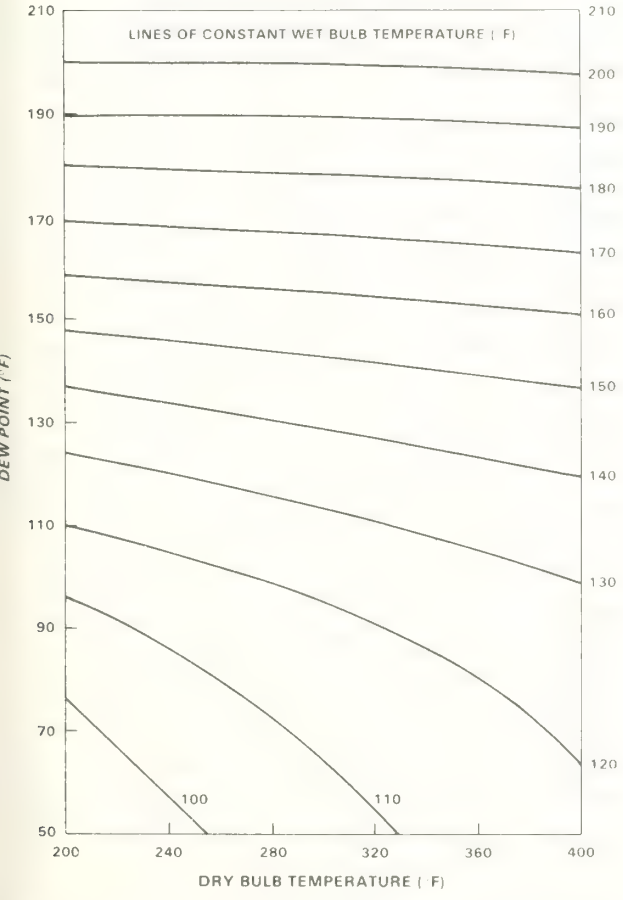

Figure 4.—*Dew point temperatures as related to wet and dry bulb temperatures (Zimmerman and Lavine 1964).*

The latent heat of condensation of water is the major portion of the total energy transferred in a regenerative heat exchanger. Almost 81 percent of the enthalpy change of water going from a vapor at 400°F to a liquid at 70°F is latent heat. When air is present with water vapor (i.e. $T_{wb}<212$°F), the contribution of latent heat to total energy recovery is not as great as in pure steam, but still can be substantial depending on conditions. As shown in figure 5, water will not condense from a humid air stream until the temperature drops below T_{dp} (For the curve at T_{wb} of 160°F, the temperature must go below 155°F). For a given T_{db} and ΔT_r, the percentage of water vapor condensed from the air stream increases as T_{wb} increases. When humid air at 250°F is lowered to 150°F, 99 percent of the water vapor is removed if T_{wb} is 210°F; whereas only 23 percent is removed if T_{wb} is 160°F (fig. 5).

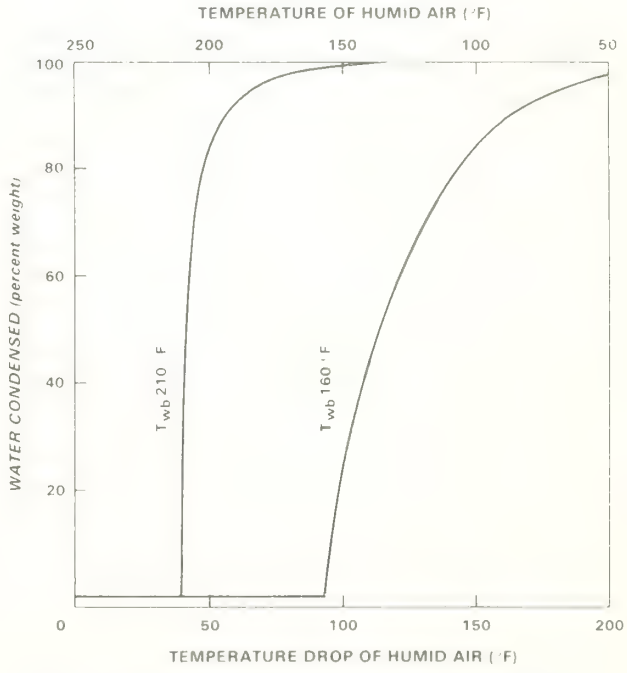

Figure 5.—*Percentages of the total water vapor in air condensed as the temperature of the air initially at 250°F is lowered.*

Typical curves from the data of the energy recovery tables show the complex relation between recoverable energy and T_{wb} for values of T_{db} and ΔT_r (figs. 6 and 7). When only sensible heat is recovered (T_{db} = 400°F, fig. 6), recoverable energy increases as T_{wb} decreases. This increase reflects the sensible heat removed with increasing amounts of dry air required per pound of water to lower the wet bulb temperature. When latent and sensible heat are removed, two types of curves result at constant T_{db}.

In most cases, a minimum recoverable energy exists at T^*_{wb} corresponding to $T_2 = T_1 - \Delta T_r = T_{dp}$. Because Δh_r at T^*_{wb} is a critical point on many of the curves, these values are given at the bottom of the energy recovery tables. Below T^*_{wb} only sensible heat is recovered; above T^*_{wb} both sensible and latent heat are recovered. The other type of curve results when the heat recovery continues to decrease over the range of T_{wb}'s even though latent heat is recovered from the air (fig. 7, ΔT_r= 180 and 200°F). In this case, as T_{wb} decreases, the

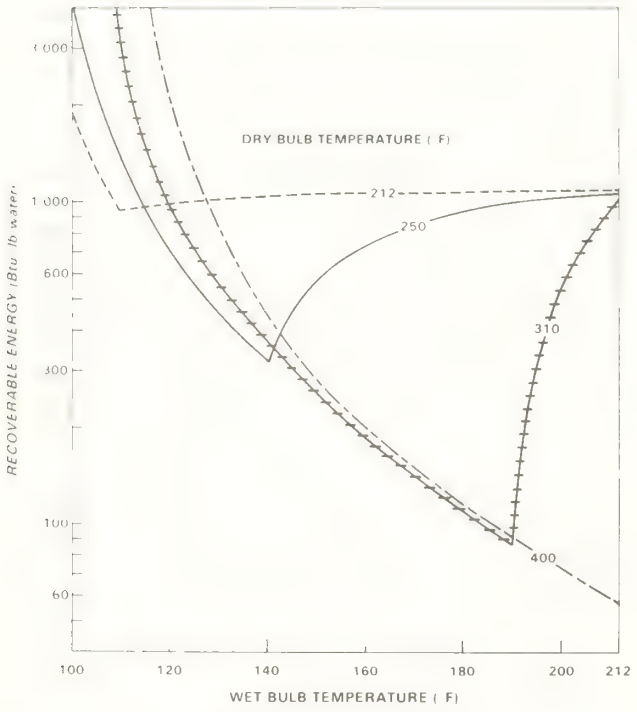

Figure 6.—*Recoverable energy versus wet bulb temperature for several dry bulb temperatures (ΔT_r = 120°F).*

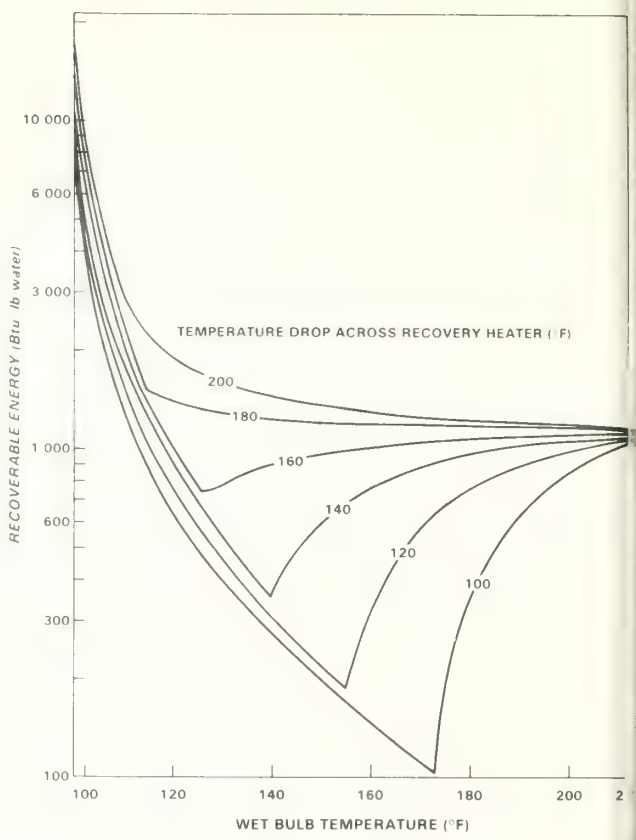

Figure 7.—*Recoverable energy versus wet bulb temperature for several temperature drops across a regenerative heat exchanger (T_{db} = 270°F).*

increasing contribution of the sensible heat of the air more than offsets the decreasing latent heat o the condensing water.

SUMMARY

An excellent potential exists for recovering en ergy from vent streams of high temperature wooc and veneer dryers. The recovery is usually im proved if the temperature of the humid air stream is lowered below the dew point so that the laten heat of the water is removed. Vent streams with high humidities are best for energy recovery, since these streams have the largest potential for ener gy recovery per volume of vent stream.

Table 1.—*Recoverable energy*[1], Δh_r, *in Btu/lb water from a heat exchanger with* $\Delta T_1 = 100°F$

Wet bulb temperature,	Vent air dry bulb temperature, T_1, °F										
T_{wb}, °F	200	212	230	250	270	290	310	330	350	375	400
100	1246	1546	2050	3437	8390	—	—	—	—	—	—
110	711	795	918	1091	1318	1660	2478	4031	11093	—	—
120	725	480	514	567	635	718	807	916	1104	1397	1924
130	850	593	343	364	390	424	460	498	543	612	689
140	920	744	317	253	265	279	293	306	320	343	368
150	968	844	543	187	195	202	209	215	221	228	235
160	1002	908	708	263	146	150	154	157	161	165	169
170	1027	968	838	564	107	109	112	115	117	119	121
180	1045	1005	915	735	351	88	91	91	92	93	94
190	1058	1031	974	851	634	71	73	73	73	73	74
200	1071	1052	1022	965	854	536	59	59	59	59	59
205		1060	1039	1004	939	760	54	54	54	54	54
210		1068	1055	1038	1013	958	50	49	49	49	49
212		1070	1061	1051	1041	1030	1019	48	47	47	47
[2]T^*_{wb}		602	423	259	157	101	68	44			
	(114)	(122)	(137)	(154)	(173)	(191)	(210)				

[1]Only sensible heat recovery above dotted line; sensible and latent heat recovery below.

[2]Recoverable energy when dew point of humid air stream is equal to T_2. The wet bulb temperature corresponding to that dew point, T^*_{wb}, is in parentheses

Table 2.—*Recoverable energy*[1], Δh_r, *in Btu/lb water from a heat exchanger with* $\Delta T_1 = 120°F$

Wet bulb temperature,	Vent air dry bulb temperature, T_1, °F										
T_{wb}, °F	200	212	230	250	270	290	310	330	350	375	400
100	1495	1855	2459	4122	10106	—	—	—	—	—	—
110	1118	938	1101	1308	1579	1988	2966	4828	13284	—	—
120	1110	1000	617	680	760	860	965	1097	1322	1679	2303
130	1106	1023	663	437	467	507	549	596	651	736	825
140	1103	1040	808	339	316	333	350	367	384	413	441
150	1102	1056	890	569	233	241	250	258	265	273	282
160	1101	1068	952	721	292	180	184	188	192	197	203
170	1100	1075	998	854	587	131	134	137	140	143	145
180	1099	1080	1028	930	747	357	107	109	111	112	113
190		1084	1049	987	876	643	85	87	88	88	89
200		1088	1066	1033	976	863	543	71	71	71	71
205		1089	1073	1050	1015	948	769	65	65	65	65
210		1090	1079	1065	1048	1023	967	59	59	59	59
212		1090	1081	1070	1060	1050	1040	1029	57	57	57
[2]T^*_{wb}		1321	917	532	312	190	121	82	59		
	(103)	(109)	(123)	(138)	(155)	(172)	(191)	(210)			

[1]Only sensible heat recovery above dotted line; sensible and latent heat recovery below.

[2]Recoverable energy when dew point of humid air stream is equal to T_2. The wet bulb temperature corresponding to that dew point, T^*_{wb}, is in parentheses

Table 3.—*Recoverable energy*[1], Δh_r, *in Btu/lb water from a heat exchanger with* ΔT_r=140°F

Wet bulb temperature,	Vent air dry bulb temperature, T_1,°F									
T_{wb}, F	212	230	250	270	290	310	330	350	375	400
100	2164	2875	4821	11716	—	—	—	—	—	—
110	1604	1288	1530	1840	2322	3454	5622	15521	—	—
120	1400	1137	795	885	1004	1123	1276	1545	1955	2689
130	1291	1113	720	544	592	638	693	760	857	963
140	1240	1117	843	368	388	406	426	449	481	515
150	1194	1110	922	588	281	290	299	309	318	328
160	1176	1108	975	750	287	211	217	223	230	237
170	1150	1103	1018	877	597	155	158	161	165	169
180	1137	1103	1045	946	760	363	126	128	130	132
190	1125	1102	1063	1001	888	655	100	102	103	104
200	1117	1102	1078	1044	987	874	550	83	83	83
205	1114	1101	1084	1061	1025	958	777	75	75	75
210	1111	1101	1089	1075	1058	1033	976	69	69	69
212	1110	1101	1091	1081	1071	1060	1049	1038	66	66
[2]T^*_{wb}	2040 (101)	1141 (111)	623 (124)	366 (139)	222 (155)	142 (173)	95 (192)	69 (210)		

[1]Only sensible heat recovery above dotted line; sensible and latent heat recovery below.

[2]Recoverable energy when dew point of humid air stream is equal to T_2. The wet bulb temperature corresponding to that dew point, T^*_{wb}, is in parentheses.

Table 4.—*Recoverable energy*[1], Δh_r, *in Btu/lb water from a heat exchanger with* ΔT_r=160°F

Wet bulb temperature,	Vent air dry bulb temperature, T_1,°F								
T_{wb},°F	230	250	270	290	310	330	350	375	400
100	3284	5505	13380	—	—	—	—	—	—
110	1893	1747	2101	2643	3942	6417	17711	—	—
120	1549	1239	1011	1142	1281	1455	1761	2232	3068
130	1388	1187	771	673	728	790	866	979	1099
140	1308	1165	891	441	463	485	510	549	588
150	1249	1150	957	606	330	340	352	364	375
160	1212	1138	1004	765	322	249	256	263	270
170	1175	1126	1041	895	605	181	185	189	194
180	1157	1122	1061	960	774	368	146	149	151
190	1142	1117	1077	1014	901	665	115	117	118
200	1131	1114	1090	1056	998	884	557	95	95
205	1128	1113	1095	1072	1035	968	785	86	86
210	1122	1111	1099	1085	1068	1042	986	79	78
212	1121	1111	1101	1091	1080	1069	1058	76	76
[2]T^*_{wb}	2511 (102)	1306 (113)	713 (126)	417 (141)	254 (156)	162 (174)	109 (192)		

[1]Only sensible heat recovery above dotted line; sensible and latent heat recovery below.

[2]Recoverable energy when dew point of humid air stream is equal to T_2. The wet bulb temperature corresponding to that dew point, T^*_{wb}, is in parentheses.

Table 5.—*Recoverable energy*[1], Δh_r, *in Btu/lb water from a heat exchanger with* ΔT_r *=180°F*

Wet bulb temperature,	Vent air dry bulb temperature, T_1, °F							
T_{wb}, °F	250	270	290	310	330	350	375	400
100	6190	15078	—	—	—	—	—	—
110	2304	2368	2979	4430	7212	19901	—	—
120	1696	1390	1287	1439	1635	1978	2512	3455
130	1480	1271	813	817	887	972	1101	1238
140	1365	1218	933	519	544	572	617	662
150	1293	1186	987	640	381	394	408	422
160	1241	1167	1026	800	277	285	295	305
170	1197	1149	1063	911	617	207	213	218
180	1175	1139	1078	977	786	176	167	170
190	1157	1132	1091	1029	889	669	130	134
200	1143	1126	1101	1067	1009	894	367	107
205	1138	1124	1106	1082	1046	978	687	97
210	1133	1121	1109	1095	1078	1052	964	89
212	1131	1121	1111	1100	1089	1078	1065	86
$^2T^*_{wb}$	2824 (105)	1472 (115)	804 (128)	472 (141)	286 (157)	183 (174)	113 (197)	

[1]Only sensible heat recovery above dotted line; sensible and latent heat recovery below.

[2]Recoverable energy when dew point of humid air stream is equal to T_2. The wet bulb temperature corresponding to that dew point, T^*_{wb}, is in parentheses.

Table 6.—*Recoverable energy*[1], Δh_r, *in Btu/lb water from a heat exchanger with* ΔT_r *=200°F*

Wet bulb temperature,	Vent air dry bulb temperature, T_1, °F						
T_{wb}, °F	270	290	310	330	350	375	400
100	16742	—	—	—	—	—	—
110	2842	3308	4929	8007	22091	—	—
120	1927	1556	1601	1814	2195	2787	3832
130	1586	1375	915	984	1078	1220	1373
140	1427	1250	990	603	634	684	733
150	1335	1219	1033	662	436	452	468
160	1271	1196	1061	814	345	323	337
170	1221	1171	1084	928	629	235	241
180	1193	1157	1096	993	793	206	187
190	1170	1145	1106	1042	924	571	147
200	1155	1137	1114	1079	1020	862	118
205	1149	1134	1117	1093	1055	963	492
210	1143	1131	1119	1105	1087	1053	917
212	1140	1130	1120	1109	1098	1085	1072
$^2T^*_{wb}$	3144 (107)	1636 (117)	895 (129)	525 (142)	319 (158)	204 (179)	115 (201)

[1]Only sensible heat recovery above dotted line; sensible and latent heat recovery below.

[2]Recoverable energy when dew point of humid air stream is equal to T_2. The wet bulb temperature corresponding to that dew point, T^*_{wb}, is in parentheses.

Table 7.—*Recoverable energy*[1], Δh_r, *in Btu/lb water from a heat exchanger with* ΔT_r=220°F

Wet bulb temperature,	Vent air dry bulb temperature, T_1, °F					
T_{wb}, °F	290	310	330	350	375	400
110	3636	5417	8819	24281	—	—
120	2389	1781	1998	2412	3062	4210
130	1844	1492	1074	1185	1340	1507
140	1577	1364	1032	697	750	805
150	1432	1280	1069	705	495	513
160	1343	1235	1086	845	354	369
170	1268	1197	1103	949	550	264
180	1226	1177	1114	1011	774	205
190	1195	1161	1121	1055	891	433
200	1170	1145	1125	1086	1009	791
205	1158	1143	1127	1103	1053	926
210	1153	1141	1128	1114	1091	1040
212	1150	1140	1129	1118	1105	1092
[2]T^*_{wb}	3457 (110)	1802 (117)	985 (130)	577 (143)	313 (162)	183 (183)

[1]Only sensible heat recovery above dotted line; sensible and latent heat recovery below.

[2]Recoverable energy when dew point of humid air stream is equal to T_2. The wet bulb temperature corresponding to that dew point, T^*_{wb}, is in parentheses.

Table 8.—*Recoverable energy*[1], Δh_r, *in Btu/lb water from a heat exchanger with* ΔT_r=240°F

Wet bulb temperature,	Vent air dry bulb temperature, T_1, °F				
T_{wb}, °F	310	330	350	375	400
110	5906	9615	26516	—	—
120	2452	2178	2633	3336	4587
130	1860	1621	1293	1460	1642
140	1577	1420	1096	817	876
150	1435	1325	1112	578	558
160	1339	1265	1121	771	401
170	1271	1220	1128	909	379
180	1232	1194	1131	989	648
190	1201	1175	1134	1049	846
200	1179	1161	1137	1094	993
205	1168	1156	1137	1111	1048
210	1162	1151	1138	1125	1088
212	1160	1149	1138	1125	1112
[2]T^*_{wb}	3777 (112)	1965 (121)	1076 (132)	554 (148)	305 (167)

[1]Only sensible heat recovery above dotted line; sensible and latent heat recovery below.

[2]Recoverable energy when dew point of humid air stream is equal to T_2. The wet bulb temperature corresponding to that dew point, T^*_{wb}, is in parentheses.

Table 9.—*Recoverable energy*[1], Δh_r, *in Btu/lb wate from a heat exchanger with* ΔT_r=260°F

Wet bulb temperature,	Vent air dry bulb temperature, T_1, °F			
T_{wb}, °F	330	350	375	400
110	10410	28707	—	—
120	2786	2851	3612	4964
130	2000	1776	1580	1776
140	1660	1494	1049	947
150	1490	1371	1081	603
160	1377	1295	1105	670
170	1297	1246	1118	852
180	1252	1215	1130	956
190	1216	1189	1135	1031
200	1191	1173	1141	1086
205	1181	1166	1144	1108
210	1172	1161	1145	1125
212	1169	1158	1145	1132
[2]T^*_{wb}	4090 (114)	2132 (123)	1022 (136)	530 (152

[1]Only sensible heat recovery above dotted line; sensible and latent hea recovery below.

[2]Recoverable energy when dew point of humid air stream is equal to T_2. The wet bulb temperature corresponding to that dew point, T^*_{wb}, is i parentheses.

Table 10.—*Recoverable energy*[1], Δh_r, *in Btu/lb water from a heat exchanger with* ΔT_r=280°F

Wet bulb temperature,	Vent air dry bulb temperature, T_1, °F		
T_{wb}, °F	350	375	400
110	30897	—	—
120	3391	3892	5350
130	2204	1855	1913
140	1753	1527	1020
150	1543	1385	1031
160	1409	1306	1075
170	1326	1252	1106
180	1274	1221	1123
190	1232	1197	1134
200	1202	1180	1144
205	1192	1173	1148
210	1182	1167	1151
212	1178	1165	1152
[2]T^*_{wb}	4409 (116)	1973 (126)	962 (140

[1]Only sensible heat recovery above dotted line; sensible and latent hea recovery below.

[2]Recoverable energy when dew point of humid air stream is equal to T_2. The wet bulb temperature corresponding to that dew point, T^*_{wb}, is i parentheses.

Table 11.—*Recoverable energy*[1], Δh_r, *in Btu/lb water from a heat exchanger with* ΔT_r=300°F

Wet bulb temperature, T_{wb}, °F	Vent air dry bulb temperature, T_1, °F 375	400
120	4168	5727
130	2419	2048
140	1829	1539
150	1578	1385
160	1438	1310
170	1338	1258
180	1261	1227
190	1232	1202
200	1211	1185
205	1199	1179
210	1189	1174
212	1185	1172
[2]T^*_{wb}	3996 (120)	1822 (131)

[1]Only sensible heat recovery above dotted line; sensible and latent heat recovery below.

[2]Recoverable energy when dew point of humid air stream is equal to T_2. The wet bulb temperature corresponding to that dew point, T^*_{wb}, is in parentheses.

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APPENDIX

I. Example problems demonstrate how to use the energy recovery tables.

Example A—A veneer dryer handles 5 tons per hour of green veneer at 80 percent moisture content and dries the veneer to 5 percent moisture content. The dry and wet bulb temperatures of the vent stacks are 290 and 190°F, respectively. Assuming that 90 percent of the water vapor removed from the veneer goes through the vent stacks (10 percent loss in leaks), how much energy can be recovered in one day from a regenerative heat exchanger designed for a 140°F temperature drop? If energy costs $3 per 10^6 Btu, what is the value of the recovered energy?

$$\text{Water removed from wood} = \frac{5 \times 2000}{1 + \frac{80}{100}} \times \frac{80-5}{100} = 4{,}167 \text{ lb/hr}$$

Water vapor through stacks = 4,167 × 0.9 = 3,750 lb/hr

Δh_r (at T_{db} = 290, T_{wb} = 190 and ΔT_r = 140 from Table 3) = 888 Btu/lb water

Total energy recovered in one day = 3,750 lb/hr × 888 Btu/lb × 24 hr/da = 0.80 × 10^8 Btu/da

$$\text{Energy savings per day} \quad \frac{0.80 \cdot 10^8 \text{ Btu/da} \cdot \$3}{10^6 \text{ Btu}} \quad \$240/\text{da}$$

Example B—Assuming that vent air at T_{db} of 270°F and T_{wb} of 180°F is passed through a regenerative heat exchanger, what is the percentage increase in energy recovery by increasing the ΔT_r from 100 to 120°F?

From fig. 7—Δh_r at ΔT_r = 100°F is 350 Btu/lb water

Δh_r at ΔT_r = 120°F is 750 Btu/lb water

$$\frac{750-350}{350} \times 100 = 114 \text{ percent}$$

II. Relation for finding W_1 above 1.0 lb water/lb dry air (Krischer 1956).

$$p_w = p_{wb} - 0.00529 \left(1 - \frac{p_{wb}}{14.7}\right)\left(1 + \frac{T_{wb} - 32}{1800}\right)(T_{db} - T_{wb})$$

$$W_1 = \frac{0.622\, p_w}{14.7 - p_w}$$

where p_{wb} is the saturation pressure of water vapor at T_{wb} (Zimmerman and Lavine, 1964).

NOTATION

Δh_{air} =Change in enthalpy of dry air, Btu/lb dry air

Δh_{cond} =Change in enthalpy of condensate, Btu/lb water

Δh_r =Change in enthalpy of the vent air stream, recoverable energy in heat exchanger, Btu/lb water

Δh_{st} =Change in enthalpy of water vapor, Btu/lb water

p_w =partial pressure of water vapor at give T_{db} and T_{wb}, psi

p_{wb} =Saturation pressure of water vapor a T_{wb}, psi

T_1 =Vent air temperature into regenerativ heat exchanger, °F

T_2 =Vent air temperature out of regenerativ heat exchanger,°F

T_{db} =Dry bulb temperature,°F

T_{dp} =Dew point temperature,°F

T_{wb} =Wet bulb temperature,°F

T^*_{wb} =Wet bulb temperature corresponding t air at T_1 with dew point at T_2,°F

ΔT_r =Temperature drop of vent air across re generative heat exchanger,°F

W =Humidity, lb water/lb dry air

W_1 =Vent air humidity into regenerative hea exchanger, lb water/lb dry air

W_2 =Vent air humidity out of regenerativ heat exchanger, lb water/lb dry air

W_s =Saturation humidity at T_2, lb water/l dry air

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Rosen, Howard H.

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OXFORD: 536.722:536:423. KEY WORDS: dewpoint, wet bulb temperature, dry bulb temperature, enthalpy, heat exchanger, humidity, psychrometry.

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MINNESOTA CANOE AND KAYAK OWNERS: THEIR CHARACTERISTICS AND PATTERNS OF USE

Earl C. Leatherberry

North Central Forest Experiment Station
Forest Service, U.S. Department of Agriculture

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MINNESOTA CANOE AND KAYAK OWNERS: THEIR CHARACTERISTICS AND PATTERNS OF USE

Earl C. Leatherberry, *Associate Geographer*

In recent years nonmotorized boating, especially canoeing and kayaking, has increased in popularity. Great numbers of new craft are appearing on the nation's lakes, rivers, and streams. Between 1973 and 1976 records show a 68 percent increase in the number of canoes, and a remarkable 107 percent increase in the number of kayaks (U.S. Department of Transportation 1978). Presently there are an estimated 1 million canoes and 90,000 kayaks nationwide.

The rapid increase in the recreational use of canoes and kayaks is of growing concern to water resources administrators. The Forest Service has had to limit use on certain waterbodies, and institute spatial and time zoning to cope with increased use. Many of these steps seem to have worked well and have public support; others have dissatisfied users and resulted in litigation (Lime 1977). Before effective and defensible decisions can be made about recreational water resource management, administrators need basic descriptive information about canoe and kayak use (Hecock 1977). The limited information that does exist pertains only to users of specific waterbodies that have specific management problems (Anderson *et al.* 1978). Water resource administrators need State-wide or regional information on which to base decisions about canoe and kayak use.

The objectives of the study reported here were to: (1) develop a means of surveying canoe and kayak owners State- or region-wide; and obtain information on (2) the socioeconomic characteristics of canoe and kayak owners; (3) the canoeing/kayaking experience of the owner; and (4) where and how much owners and their families used their craft from April through October 1977.

STUDY PROCEDURES

Minnesota, a State with a long-standing water recreation tradition, is one of five States (Arizona, Oklahoma, Ohio, and Iowa) that presently requires the registration of paddle canoes and kayaks. Over 95,000 paddle canoes and kayaks, are registered with the Minnesota Department of Natural Resources. Approximately 28 percent (26,500) of the registered paddle canoes and kayaks are classified as commercial or belonging to nonprofit organizations such as the Boy Scouts. The remaining 68,500 craft were owned by both Minnesota residents and nonresidents.[1] For purposes of this paper, only the craft whose owners resided in Minnesota at the time of registration were included in the study population. As of January 1977, the registration files contained 65,695 such craft.

To obtain accurate information about both canoe and kayak owners the population was stratified by craft type. There were 64,118 paddle canoes and 1,577 kayaks. It was believed that a 1 percent sample of canoes and a 10 percent sample of kayaks would be sufficient to represent the population of canoe and kayak owners. To select the sample for canoes, a random number between 1 and 100 was picked and every one-hundredth name thereafter was selected as part of the sample. For kayaks a random number between 1 and 10 was selected and every tenth name was selected.

---

[1]*Nonresident boat owners whose craft are not registered in their home States are required to register with the Minnesota Department of Natural Resources when their craft are used on Minnesota waters.*

To insure against double sampling a particular name and address was selected only once. To eliminate confusion for multi-craft owners individuals were instructed to answer the question for the craft whose registration number appeared on the questionnaire.

Each sampled owner's name and mailing address was printed on self-adhesive labels. These labels were transferred to envelopes for mailing the questionnaire and subsequent follow-up reminders to nonrespondents. The initial mailing to canoe owners, and two follow-ups to nonrespondents, resulted in 460 usable questionnaires out of 593 delivered for a 78 percent response. For kayak owners, the initial mailing and two follow-ups provides 98 usable questionnaires out of 144 delivered, resulting in a 68 percent response.

RESULTS AND DISCUSSION

Socioeconomic Characteristics

Canoe and kayak owners' socioeconomic characteristics and those of all Minnesotans are summarized in table 1. The Kolmogorov-Smirnov test was used to test differences (5 percent level of significance) in the distribution of the quantitative variables obtained from the study population. Caution should be used in comparing the data in table 1 with similar breakdowns published in other recreation studies. The socioeconomic data presented in the table represent the socioeconomic characteristics only of the *owners* of the craft (not necessarily the users).

Canoe and kayak owners were mainly young and middle-aged adults. On the average, kayak owners were younger (37 years) than canoe owners (39 years) and both were younger than the general population of Minnesota (table 1). Canoe and kayak owners were concentrated in the middle-age categories while the general population of Minnesota included a higher proportion of both older and younger persons.

The level of education achieved by canoe and kayak owners was greater than that achieved by the Minnesota population (table 1). Average number of years of school completed was 15.1 by kayak owners, 14.5 by canoe owners. In terms of formal education, canoe and kayak owners are similar to people who participate in backcountry recreation (Hendee *et al.* 1968, Murray 1974).

Over a third of the canoe and kayak owners had "professional" or "technical" occupations (table 1). However, a large proportion of the kayak owners (16 percent) were students, as opposed to only 2 percent of the canoe owners.

Canoe owner families had higher average annual family incomes for 1976 than did kayak owner families. Three-fourths of the nonstudent canoe owner households had incomes in excess of $15,000 compared to two-thirds of the nonstudent kayak owner families (table 1). The proportion of canoe and kayak owner families making over $15,000 annually far exceeded the proportion of families in the north-central region making a like amount. The contrast is even more dramatic when it is noted that regionally one-fifth of all families had annual incomes in excess of $25,000 while about a third of the canoe and kayak owner families had incomes exceeding $25,000 annually.

Canoe and kayak owners were primarily city residents. Approximately half of Minnesota's population is concentrated in the Minneapolis-St Paul metropolitan area and nearly one-half (46 percent) of the canoe owners and a full two-thirds of the kayak owners lived in the Minneapolis-St Paul metropolitan area. Approximately 15 percent of both canoe owners and kayak owners lived in rural areas. Many of the rural residents apparently did not live on working farms. This is partially shown by the low proportion of craft owners who were farmers, relative to the proportion of rural residents.

Canoeing/Kayaking Experience

Experience was measured in terms of the average age of the owners when: (1) they went on their first canoe/kayak outing; (2) the activity became an important recreational pursuit; and (3) they acquired their first craft. Membership in canoe/kayak organizations, and ownership of other watercraft were also viewed as indicators of experience.

Canoe owners, on the average, went on their first canoe outing when they were 20 and kayak owners when they were 26 (table 2). A third of the kayak owners were over 30, and a fifth of the canoe owners were over 30 when they went on their first

Table 1.—*Socioeconomic characteristics of Minnesota canoe and kayak owners' compared to Minnesota residents*

Socioeconomic characteristics	Canoe owners	Kayak owners	Minnesota population
	Percent (N=452)	Percent (N=96)	Percent (N=2.9 million)[1]
AGE			
15 to 24 years	10	21	27
25 to 34 years	28	34	19
35 to 54 years	50	44	27
55 to 64 years	9	7	12
65 or more	3	4	15
EDUCATIONAL ATTAINMENT	(N=453)	(N=96)	(N=2.2 million)[2]
Less than 9 years	2	1	19
Some high school (9 to 11 years)	4	4	11
Completed high school (12 years)	20	9	39
Some college or equivalent (13 to 15 years)	29	34	14
Completed college (16 years)	13	10	10
Post Graduate (17 years or more)	32	41	7
OCCUPATION	(N=446)	(N=94)	(N=3.1 million)[3]
Professional, technical	35	37	17
Managers, administrators	12	6	5
Clerical, sales workers	14	9	20
Crafts	14	15	13
Operatives	7	0	15
Nonfarm laborers	3	2	5
Service workers	4	3	16
Farm workers	2	2	9
Students	2	16	N/A
Others	4	6	N/A
Retired	3	3	N/A
FAMILY INCOME, 1976	(N=418)[4]	(N=75)[4]	NC Region[5]
Under $3,000	0	3	3
$3,000-$9,999	9	13	23
$10,000-$14,999	16	17	20
$15,000-$24,000	43	36	34
$25,000 and above	32	31	20

[1]Source: Minnesota State Planning Agency, Office of State Demographer. 1978. Minnesota population projections 1970-2000.

[2]Source: Minnesota State Planning Agency, Office of State Demographer. 1978. Educational Attainment in Minnesota 1977. (includes only those residents 25 years and older)

[3]Source: Minnesota Department of Economic Security, Research and Planning. 1978. Minnesota Employment Trends, 1974-1975.

[4]Student portion of the sample excluded.

[5]Source: U.S. Department of Commerce, Bureau of the Census. 1977. Statistical Abstract of the United States, 1977. Data not available for Minnesota alone North Central Region includes Minnesota and other Upper Midwestern States.

Table 2.—*Chronological profile of Minnesota canoe and kayak owners' experience*

Experience	Canoe owners[1]	Kayak owners[2]
	years	*years*
Age when first outing occurred	20	26
Age when activity became an important recreation pursuit	27	27
Age when first craft was acquired	31	29

[1]Average age 39.
[2]Average age 37.

outing. Compared with most other outdoor recreation activities, canoeing and kayaking are activities people get acquainted with later in life. For example, Hendee *et al.* (1968) found that 70 percent of the wilderness users interviewed indicated they went on their first trip to backcountry areas before they were 15 years old. Klessig and Hale (1972) found that 90 percent of the hunters they interviewed started hunting before they were 20 years old.

Both canoe and kayak owners, on the average, were 27 when they perceived their activities as being an "important" part of their recreational pursuits. The definition of importance was self defined — respondents were asked, "what age were you when canoeing or kayaking became an important part of your recreation activity?" Interestingly, 6 percent of the canoe owners and 13 percent of the kayak owners indicated that their respective activity was not an important recreation pursuit. These owners were probably not the primary user of the craft.

Canoe owners acquired their first canoe when they were 31 and kayak owners acquired their first kayak when they were 29. The acquisition of a craft is probably related to confidence in the ability to use the craft properly, or to learn to use it properly (18 percent of the kayak owners acquired their craft an average of 3 years before the activity became important).

Both canoe and kayak owners had low membership rates in canoe/kayak "user" organizations. Only 1 percent of canoe owners in this study were members of canoe clubs; more kayak owners (14 percent) were affiliated with kayak groups. Canoe and kayak owners appear to be similar to recreationists, such as automotive campers, who generally are not affiliated with "user" organizations.

The ownership of other watercraft serves to underscore canoe and kayak owners' interest and involvement in waterbased recreation. Half of the canoe owners and two-thirds (67 percent) of the kayak owners owned other registered watercraft (table 3).

Table 3.—*Percentage of canoe and kayak owners owning other registered watercraft*

Craft	Canoe owners[1]	Kayak owners[2]
	Percent	
Kayaks	< 1	14
Canoes	12	43
Sailboats	10	16
Motorboats	22	15
Rowboats	23	17
Pontoon	2	< 1
Others	3	11

[1]N=460. (From the sample of canoe owners, 231 (50 percent) owned other craft.)
[2]N=98. (From the sample of kayak owners, 66 (67 percent) owned other craft.)

Use Characteristics

Information about use characteristics was sought for the period, April to October 31, 1977, roughly the open-water season in Minnesota. One fourth of the kayak owners and 15 percent of the canoe owners reported their craft were not used in 1977. The socioeconomic variables — age, education, occupation, income, and place of residence — were tested with chi-square analyses to determine if they had an influence on whether or not the canoe or kayak was used in 1977, but no significant associations were found (5 percent level). The remaining findings refer only to those owners who reported their craft was used by household members in 1977.

In this study two measures of use were employed. First, total use was measured in terms of the number of times the canoe or kayak was launched in 1977. Second, the number of days, or

portion thereof, the canoe or kayak was used on each of the following: anywhere within the Boundary Waters Canoe Area (BWCA) lakes; rivers; wetlands. If the craft was used on more than one type of water body on the same day respondents were told to count one day of use for each type of water body used.

The average kayak was launched 32 times as opposed to 22 times for canoes. The highest proportion of launches for both craft types were in the 1-10 range which included 41 percent of the canoes and 30 percent of the kayaks. Nearly a fifth (17 percent) of the kayaks were launched over 60 times indicating a zealous cadre of kayakers.

The socioeconomic variables were tested independently to determine if they were related to how much the canoe or kayak was launched but no statistically significant associations were found. However, three measures of "experience" did relate to the number of times the canoe was launched. Experience was expressed in terms of the owners age: (1) when the first canoe outing occurred; (2) when canoeing became important, and (3) when the first canoe was acquired. Canoe owners who were under 30 when they experienced each of the three events reported their crafts were used significantly more than those owners who were over 30 when they experienced them. In the case of kayak owners, only the age of first outing was related to the number of times the craft was launched. Those owners who went on their first outing before they were 30 launched their kayaks significantly more than those kayak owners who were over 30 when they first went.

Most canoes and kayaks were launched during the months of June, July and August. The proportion of canoes and kayaks launched were greater during July, but fall launches were also numerous (table 4). In general, the proportion of kayak owners reporting their crafts launched during a particular month was greater than canoe owners, except during October. The canoes and kayaks that were launched during a particular month were launched an average of at least five times, except during April. During June over three-fourths of the kayaks were launched an average of 9.4 times. In July more people launched their kayaks but on fewer occasions. July was the peak month for canoe launches. October had a high

Table 4.—*Percentage of canoes and kayaks launched each month and the average number of launches per month, April-October 1977*

Month	Canoes[1]		Kayaks[2]	
	Percent	Number	Percent	Number
April	15	4.3	25	4.5
May	48	5.1	66	5.5
June	75	6.2	77	9.4
July	81	6.8	89	8.5
August	70	6.4	75	8.7
September	43	5.8	49	7.0
October	23	6.5	22	7.6

[1]N=390.
[2]N=73.

average number of launches; waterfowl hunting by a minority of families probably accounted for much of this use.

Eight out of every 10 canoes and kayaks was used on lakes, the principal places of use (table 5). Those canoeists who used lakes used them for about 17 days and kayakers about 20 days. Rivers and streams were also used substantially — by more than half the canoeists and kayakers. Kayakers were more river-oriented than canoeists and those who used rivers used them substantially more than did canoeists. Wetlands — swamps, marshes, and sloughs — and the BWCA were used considerably less than rivers and lakes. Wetlands were used by 15 percent of the canoeists and kayakers; kayakers, however, used their craft on wetlands about a day more than canoeists. A fifth (22 percent) of the canoes were used in the BWCA; the area was not as attractive to kayakers — only 14 percent reported their craft were used there. Nevertheless, in terms of average number of days used in 1977, wetland and BWCA use was relatively high. When one considers the relative scarcity of these resources, the average number of days used is noteworthy. BWCA use is especially noteworthy because most Minnesota canoe and kayak households live far from the BWCA.

Most canoeists and kayakers use more than one type of water body. However, about a third of both canoe and kayak owners said their craft were used only on lakes, and about a tenth of both said rivers only. Less than 2 percent of both said their craft were used only in the BWCA or in wetlands.

Table 5.— *Percentage of canoes and kayaks used on different water bodies and average number of days used each, April-October 1977*

Water Bodies	Canoes[1]		Kayaks[2]	
	Percent used	Average number of days used	Percent used	Average numb of days use
Lakes	85	16.7	84	19.8
Rivers and streams	57	7.9	62	20.1
Wetlands (swamps, marshes, sloughs)	15	6.0	15	7.4
Boundary Waters Canoe Area	22	9.8	14	7.1

[1]N=390.
[2]N=73.

About a third of the kayak owners and a fifth of the canoe owners stated their craft were used out of Minnesota. Rivers in Wisconsin, and the lakes of nearby Quetico Provincial Park in Canada, were the most commonly used places outside of Minnesota.

IMPLICATIONS FOR MANAGEMENT

Developing Facilities for Waterbased Recreation

Management agencies could make the variety of waterbased recreation for canoeists and kayakers even greater and provide more opportunities for the high proportion of owners who reside in the Minneapolis-St. Paul Metropolitan Area. Encouraging urban waterbased recreation could alleviate pressures on more remote and sensitive waters. Close-in small urban streams, such as Minnehaha Creek in the southern suburbs and south Minneapolis, and Rice Creek in the north suburbs, provide the opportunity to experience near-natural environments despite the high population density. These and other such streams, or portions thereof, could be managed and promoted for nonmotorized recreation. Large rivers such as the Mississippi and Minnesota in the Twin Cities, and the St. Louis in the Duluth area, could be managed to accommodate more nonmotorized use, especially during periods when commercial traffic or other activities are low, such as on weekends. Lack access for motorized craft have often limited n torized use on urban rivers. These stretches co be promoted for nonmotorized use. However, fore this can happen instream pollution must curbed.

Most owners indicated their craft were used lakes. Lakes are also used by waterskiers, b fishermen, and motorboats. The potential for c flict is present; as use increases so will act conflicts. In the future it may be necessary to z some lakes to eliminate conflicts. Water surfa should be zoned by time, rather than by spa Time zoning would work best because the major of canoe and kayak owners also own other wat craft. Many of these owners may live on or n lakes or may have summer homes on or near lak Spatial zoning would curtail or restrict the us some craft but time zoning would allow seve kinds of watercraft on the same lake, but at diff ent times of the day.

Most canoe and kayak owners got involved their respective boating activities before they quired their first craft. To participate, a portio them either borrowed or rented craft. Canoe a kayak rental agencies have an important imp on development; managers can influence and rect their impact by establishing criteria un which they must operate. For example, can kayak rental should be encouraged to locate waters especially well-suited to nonmotori boating. Encouragement could come in the for technical or financial assistance. For exam

nanagers could provide local entrepreneurs with oncessionaire rights at parks or along water vhere use is currently light.

Water resource administrators often point out hat funds are inadequate for a particular recrea- ion facility. Canoe and kayak owners in this study vere from relatively high income households. The ossibility of instituting user fees for certain facili- ies should be explored. A recent study of Minneso- a's Kettle River users revealed that canoe club nembers were willing to pay to use the river and or campsite construction but users who were non- lub members were not (Ballman *et al.* 1978).

More innovation and coordination is needed mong agencies that manage waterbased recrea- ion. To maintain diversity, it may be necessary or agencies such as the Forest Service and the 'ish and Wildlife Service, that control large ex- anses of land to manage that land for more dis- ersed or "wilderness" waterbased recreation.

The student population among the kayak own- rs was relatively large. The proportion of young dults in the population has leveled off and is xpected to decline during the next decade. Water esource managers should be particularly cau- ious of projecting past participation patterns into he future, especially since students tend to be ransitory and have a high propensity for being addish. This may be exemplified in the fact that ully one-fourth of the kayak owners stated their raft were not used.

Information and Interpretive Services

Management agencies need to find innovative ways of securing input from potential users. For example, the Minnesota Department of Natural Resources tries to obtain input and assistance rom the public when developing management lans for rivers considered for inclusion into the Minnesota Wild and Scenic Rivers program. Pub- ic hearings and information meetings are held in ocal communities near the river. These meetings re generally well attended by local people who nake their feelings known. Most craft owners do ot live near proposed rivers and do not belong to anoe or kayak clubs. Often their feelings concern- ng designation is not heard. Admittedly, canoeing and kayaking are probably not their only recreational pursuits. But to have a well-accepted and developed program input should be solicited from all potential users. Advertising and public involvement meetings held at nonconventional places and time, such as during "lunch hours" at downtown locations in the Twin Cities, or college campuses, may be a viable option.

People may go to a particular water body because it is familiar and because they know little about alternatives. A recent study evaluating the effectiveness of a brochure sent to BWCA users describing alternative routes and attractions indicated that information can be a desirable management technique to disperse use and to help recreationists find locations that match their desires (Lime and Lucas 1977). Canoe and kayak owners in the present study were highly educated and professionally oriented, and it seems likely they would be receptive to a wide range of informational materials in planning trips. Information could be presented through various media and could contain technical information, such as the "difficulty rating" for whitewater canoeing or kayaking, illustrated and explained.

On-site displays and interpretive facilities should be well designed to appeal to the user. Poorly displayed or over-simplified materials may be ignored. For example, traditional presentations of safety tips, such as cartoons and so-called "scare tactics" might not be as effective as more factual approaches. The maturity of users, in conjunction with their relatively high education, suggests the use of more sophisticated media presentations. Furthermore, on-site interpretation with users participating may be more appealing and informative. On heavily used waters, it may be advantageous to have roving "rangers" in canoes or kayaks who could give impromptu interpretation and information. This type of service should be low key and offered only when users appear interested or seek advice or assistance.

Safety Education

Canoeing and kayaking require considerable skill and knowledge of water safety. The rapid growth of these activities and the accompanying high accident rate seem to indicate the need for stronger safety education programs. (The results of U.S. Coast Guard study shows that in 1973, in

terms of amount of time engaged in boating, passengers in paddle canoes had the highest fatality rates, 1.21 deaths per million (U.S. Department of Transportation 1978).) Safety education should be an important part of water recreation management.

Management agencies and rental agencies need to work together to promote safety education because many people probably start canoeing and kayaking by renting or borrowing their craft. Training assistance and literature for distribution to users could be furnished to rental agencies. There are two advantages to this approach: (1) the user is contacted early, and (2) the message is conveyed by the private sector — which may enhance acceptability.

Management agencies could promote safety by providing incentives. For example, owners who could prove that craft users have taken a water safety course could be granted a reduction in license fee. Users could also be required to show proof of ability to float certain high risk rivers. About a fifth of the kayak owners were students. Most universities and some high schools offer courses through their physical education departments or outdoor recreation programs that teach canoeing and kayaking skills. These courses should be recognized by management agencies; agency personnel could become involved in course design and in monitoring these courses.

Although most canoeists and kayakers use lakes at present, there will be a need for transition training because river use is expected to increase. Some skills that are used for lakes are not suitable for rivers and users must be trained to make the transition from lakes to rivers a safe one.

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Man paints houses...

only nature should paint

trees and rocks.

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The economic and geographic IMPACT of national forest land on counties in southern Illinois

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THE ECONOMIC AND GEOGRAPHIC IMPACT OF NATIONAL FOREST LAND ON COUNTIES IN SOUTHERN ILLINOIS

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The USDA Forest Service is concerned with the possibility of negative economic effects of National Forests on local economies. Legislation has been introduced repeatedly in recent years seeking to change the present method of revenue sharing with State and local governments. The reason is that tax losses to local government supposedly occur as a result of the tax immunity of federal land.[1]

The purpose of this study was to explore the relation of public land to a local economy; the results have implications for the broader problem. The study region was southern Illinois, the public land, the Shawnee National Forest. Other types of public land in southern Illinois, such as the 44,000-acre Crab Orchard Wildlife Refuge, were considered only peripherally.

Assessing the relative economic effects of public land is difficult because data are hard to gather and measure consistently. However, some conclusions were reached that shed light on the regional issue and will perhaps contribute to the resolution of this problem nationally.

[1]*The House Committee on Insular Affairs held hearings on this subject during the summer of 1974. At that time 14 bills had been introduced that would change revenue-sharing systems on Federal land. Since that time, several more bills have been introduced, most notably H.R. 9719, which would give local government a choice between a minimum payment per acre or revenue-sharing payments.*

THE STUDY SCOPE

The geographic focus was the 11-county area comprising the southern tip of Illinois. Ten of the 11 counties contain areas of the Shawnee National Forest of varying size. The eleventh county, Pulaski, is not within the purchase area of the forest; however, it is included as a control since it is similar in all other respects. The 11 counties are Alexander, Gallatin, Hardin, Jackson, Johnson, Massac, Pope, Pulaski, Saline, Union, and Williamson. The study region (fig. 1) is largely rural, bounded on two sides by the Ohio and Mississippi Rivers; it covers roughly 3,748 square miles. The terrain consists primarily of unglaciated hill country, which gives way in the larger river valleys to low gravel hills and swampy, forested bottomland.

The economy of the region depends primarily on mining, agriculture, some manufacturing, and the presence of several large institutions, including a state university, two prisons, and a large state hospital.

Purchase of land for the Shawnee National Forest (fig. 2) was begun in 1933; about 87 percent of the land was purchased before World War II (Callahan *et al.* 1974). The forest presently contains 254,167 acres, of a total of 839,735 acres within the purchase area.

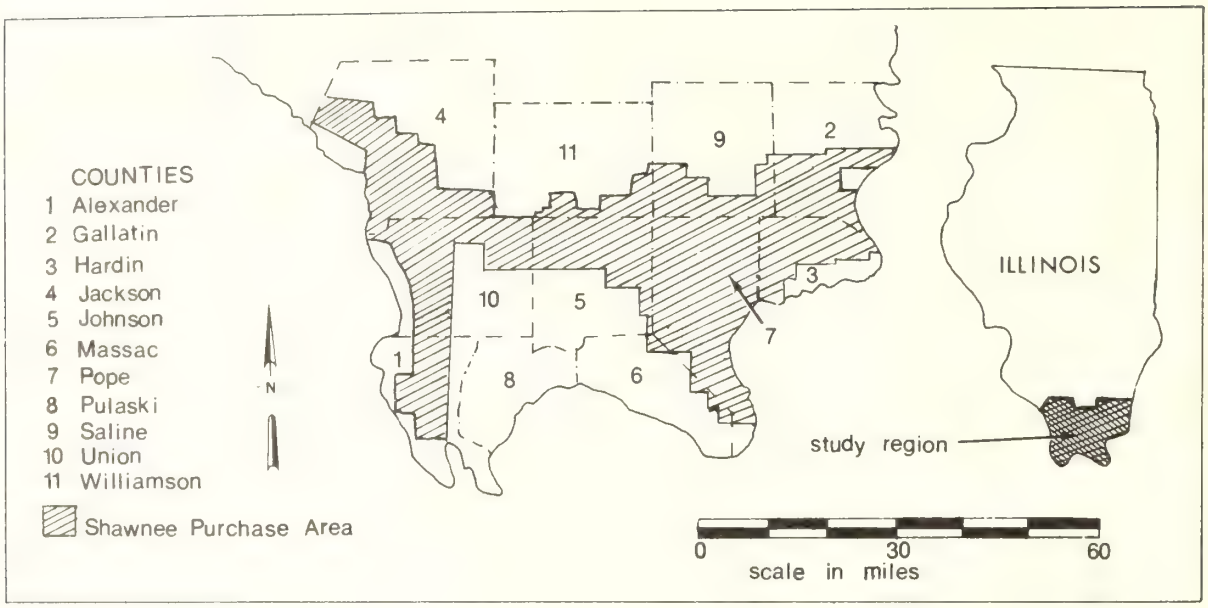

Figure 1. — *The study region.*

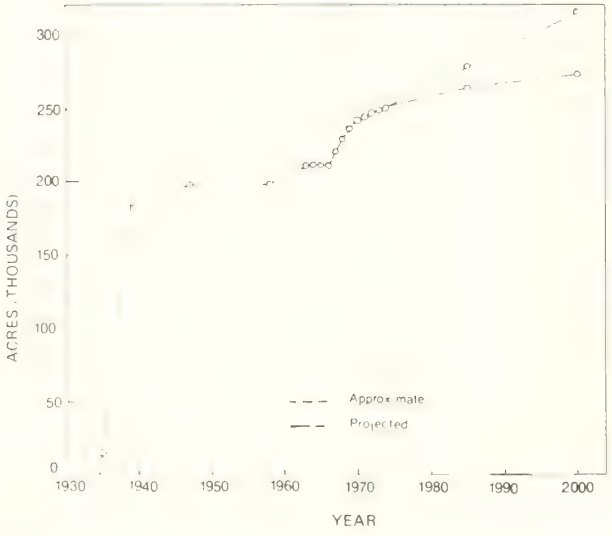

Figure 2. — *Land acquisition on the Shawnee National Forest (Callahan* et al. *1974).*

At present some counties are resisting further purchases by the Forest Service because they contend that removal of land from the tax rolls and other negative economic effects are seriously affecting the general economic welfare of the region — this belief relates, in part, to the National Forest revenue-sharing program. The revenue of the Shawnee National Forest is low compared with other National Forests, and as a result of this, revenue sharing funds are low. The reason, according to Callahan *et al.* (1974), is that "land ownership is scattered and the emphasis on timber production is low, while the emphasis on recreation and wildlife activities which tend to be non-revenue generating is high."

Of the 10 counties within the purchase area, Pope County has the largest percentage of its area in National Forest and has received the most attention both locally and nationally. For example, in an NBC news program aired in 1975, local residents blamed the presence of the National Forest for a variety of county ills, ranging from insolvency of the county government to an increase in coyote populations causing destruction of livestock. In October of 1975 the Illinois Legislature passed an emergency loan of $140,000 so that the County could pay its 1975 tax fiscal-year bills. William Leach, Assistant County Commissioner, said in an interview in October, 1975: "The County corporate fund has an annual deficit of $150,000 . . . Alternative solutions are a new taxation, a State cost-sharing program for County programs, or authorization for Federal in-lieu-of tax payments of $1.50 per acre." These sentiments are echoed throughout the region by State and local officials and by many members of the public.

In spite of the above, the degree of contribution, if any, of the National Forest to these problems has not been established. The intent of this study was to evaluate the gains and losses to the people of southern Illinois resulting from land acquisition by the Forest Service, and to assess the economic impact of the Forest in its present condition.

To meet these objectives, the problem was approached from two perspectives. First, the socioeconomic structure of the study region was explored, with special emphasis on how the Shawnee National Forest interacts with this structure. Second, specific effects of the National Forest on county finances were analyzed.

Three hypotheses were constructed and tested to meet the objectives:

1. The socioeconomic structure of southern Illinois is sufficiently homogeneous to be analyzed systematically.
2. The Shawnee National Forest has a significant effect on the socioeconomic structure of the region.
3. The Shawnee National Forest has a negative effect on individual welfare, regional economic welfare, and local governmental welfare in southern Illinois.

STATISTICAL METHODS OF ANALYSIS

The Data Base

Socioeconomic data were collected on 26 variables for each county in the study region. (A complete list appears in Appendix A.) Most of the data were compiled from United States Census material, which represents the most current information available. Success in obtaining observations on each variable was generally high and thus few cases of missing data exist.[2]

[2]*It should be noted that the number of observations on each variable is rather small (11 per variable, corresponding to the 11 counties). This, however, is not a sampling problem because these observations have been taken on the total population of counties in the region. The 11 counties studied do not represent a larger population of counties outside the study region, therefore the population of 11 counties is a total enumeration.*

Steps in Analysis

The raw data collected were assimilated in two steps. In the first step the data were compiled visually and graphically to ascertain how the counties stand in relation to one another on a variable-by-variable basis. Along with this cross-county analysis, an intercorrelation matrix of 17 variables was constructed using a Spearman rank correlation procedure (see Appendix B, table 1). This intercorrelation matrix was further modified using partial correlation analysis to eliminate variables that measure the same attributes or mask relations among other variables (see table 1).

It became apparent during this analysis that while some insights into the socioeconomic structure of southern Illinois were being obtained, this approach was not providing the most useful information overall. It was felt that multiple factor analysis could "collapse" the shared variance of the most meaningful variables into several recognizable dimensions that would be more useful. Hence, the second step in the data interpretation: a multiple factor analysis.

The factor analysis was done to determine the variations in economic welfare among counties and to show these factors visually, in a form that could be compared against the distribution of Forest Service land.

A factor may be defined as a vector of interrelation among several variables that are associated with the factor positively or negatively and that exhibit variable strengths of relation to that vector. These measures of relation of the factor to each variable are called "loadings". Thus, in describing a factor, those variables upon which it "loads" most highly indicate to some extent the nature and character of that factor. The intercorrelation matrix was analyzed using Rao's Canonical Factor Analysis with an oblimin rotation. Factor scores were then produced for each factor on all observations. Factor scores measure the strength of relation of each factor to each observation, in this case to counties. The results were used to map the factors in relation to the distribution of Forest Service land. This mapping process was accomplished using a SYMAP program (the quantitative methods used are discussed in detail in Appendices B and C).

Table 1. — *Intercorrelations of variables used in factor analysis*

	Variable	V_1	V_2	V_6	V_9	V_{11}	V_{17}	V_{19}	V_{21}	V_{23}	V_{26}
V_1	County population, 1970	1.0	0.80	−0.55	0.78	0.52	0.88	0.94	0.97	−0.33	0.76
V_2	Mean county income, 1970	.80	1.0	−.88	.77	.66	.73	.78	.75	−.32	.66
V_6	Percentage of the county population below the U.S. poverty level, 1970	−.55	−.88	1.0	−.63	−.56	−.47	−.57	−.54	.35	−.45
V_9	County area in acres	.78	.77	−.63	1.0	.70	.58	.73	.65	.003	.53
V_{11}	Number of acres classified as tillable in the county, 1969	.52	.66	−.56	.70	1.0	.40	.50	.37	−.32	.38
V_{17}	Number of manufacturing plants employing more than 20 people, 1972	.88	.73	−.47	.58	.40	1.0	.82	.92	−.39	.78
V_{19}	Median school years completed, 1970	.94	.78	−.57	.73	.50	.82	1.0	.93	−.34	.69
V_{21}	Total county tax revenues, 1972	.97	.75	−.54	.65	.37	.92	.93	1.0	−.38	.78
V_{23}	Percentage of county area in National Forest	−.33	−.32	.35	.003	−.32	−.39	−.34	−.38	1.0	−.23
V_{26}	Total per capita county retail sales, 1972	.76	.66	−.45	.53	.38	.78	.69	.78	−.23	1.0

Results of the Factor Analysis

The initial comparisons between variables, described above, indicated that a wide disparity in resources, wealth, and economic activity exists among the 11 counties in the study area. For example, more than 50 percent of the total property taxes of all 11 counties are collected in two Counties, Jackson and Williamson. The economically marginal nature of several other counties in the study area does not, however, necessarily correspond to greater amounts of Forest Service land. Jackson County has a relatively high level of economic welfare and also the second greatest amount of Forest Service land. Pulaski County, which has no National Forest lands, has one of the lowest levels of economic welfare. These circumstances indicate that there are more complex, underlying reasons for the National Forest's apparent association with economic problems in certain counties. The factor analysis was a necessary procedure in delineating these complex relations.

In this section each factor identified in the analysis is discussed and a computer-generated map of the theoretical distribution of that factor is presented. It should be noted that the results are not absolute in any sense, and the factors and maps are simply tools to help understand a complex situation. The inclusion of more variables might change the analysis somewhat, but probably not substantially. The variables used can be considered representative and capable of bringing into focus some of the major economic forces operating in the study region. The rotated factor loadings are presented in table 2.

Factor One: Urban Economic Activity

This factor has a strong positive association with total county population, manufacturing, total tax revenue, and retail sales. Because it relates strongly to high population and sophisticated economic activity this is an urban factor. It shows little association with tillable acreage, indicating that it is not related to agriculture, and further reinforcing the urban nature of the factor. The tabulation below shows the relations of factor one to each variable, expressed as factor loadings:

Table 2. — *Rotated oblique factor pattern loadings*

Variable		Factors indentified by numbers and descriptive name				
		Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
		Urban economic activity	Individual income	Density of National Forest ownership	Educational opportunity	Agricultural intensity
V_1	County population, 1970	0.445	0.035	−0.052	0.487	0.165
V_2	Mean county income, 1970	.332	.677	−.021	−.026	.147
V_6	Percentage of the population below the U.S. poverty level, 1970	.073	-1.024	.045	.021	.017
V_9	County area in acres	.086	−.190	.353	.349	.568
V_{11}	Number of acres classed as tillable in the county, 1969	−.013	.010	.112	−.051	.947
V_{17}	Number of manufacturing plants employing more than 20 workers, 1972	1.088	.049	−.041	−.130	.032
V_{19}	Median school years completed, 1970	.241	.131	.137	.622	.091
V_{21}	Total county tax revenues, 1972	.588	.089	−.110	.420	−.069
V_{23}	Percentage of county area in National Forest	−.045	−.059	.851	−.040	−.076
V_{26}	Total per capita retail sales, 1971	.754	.096	.024	.001	.003

Variable		Loadings of factor one, urban economic activity
V_1	County population, 1970	0.445
V_2	Mean county income, 1970	.332
V_6	Percentage of the population below the U.S. poverty level, 1970.	.073
V_9	County area in acres	.086
V_{11}	Number of acres classed as tillable in the county, 1969	−.013
V_{17}	Number of manufacturing plants employing more than 20 workers, 1972	1.088
V_{19}	Median school years completed, 1970	.241
V_{21}	Total county tax revenues, 1972	.588
V_{23}	Percentage of county area in National Forest	−.045
V_{26}	Total per capita retail sales.	.754

Of most interest to this study is the extremely low loading on the National Forest variable. This variable has the highest negative value, indicating that while the National Forest's effect on urbanization is relatively neutral, National Forest Land and urbanization are generally not compatible. In effect, as urbanization increases so does the intensity of land use, resulting in land less suited to the extensive management the Forest Service practices. This is illustrated by a similar loading for agriculture (variable 11). The effect of extensive versus intensive land use is also important to the factor's relation with agriculture.

The factor map (fig. 3) is based on a standardized factor score for each county. This score was placed at the point of highest population in the county (in most cases the county seat); the resultant map gives some indication of the intensity of this factor throughout the study region (see Appendix C for details of mapping procedure).

Areas appearing darkest on the map are the most urban and have the highest levels of economic activity. Only Jackson and Williamson Counties fall into the strongly urban category. Massac, Saline, Union, and Alexander Counties are primarily semi-rural counties with an intermediate amount of economic activity. Hardin, Pope, Gallatin, Johnson, and Pulaski Counties are completely rural counties, and have relatively low levels of economic activity. This factor accounts for 66.4 percent of the variance among the counties on these variables. The low loading on the variable measuring the influence of the National Forest is important with respect to this factor. The factor itself strongly indicates that the degree of

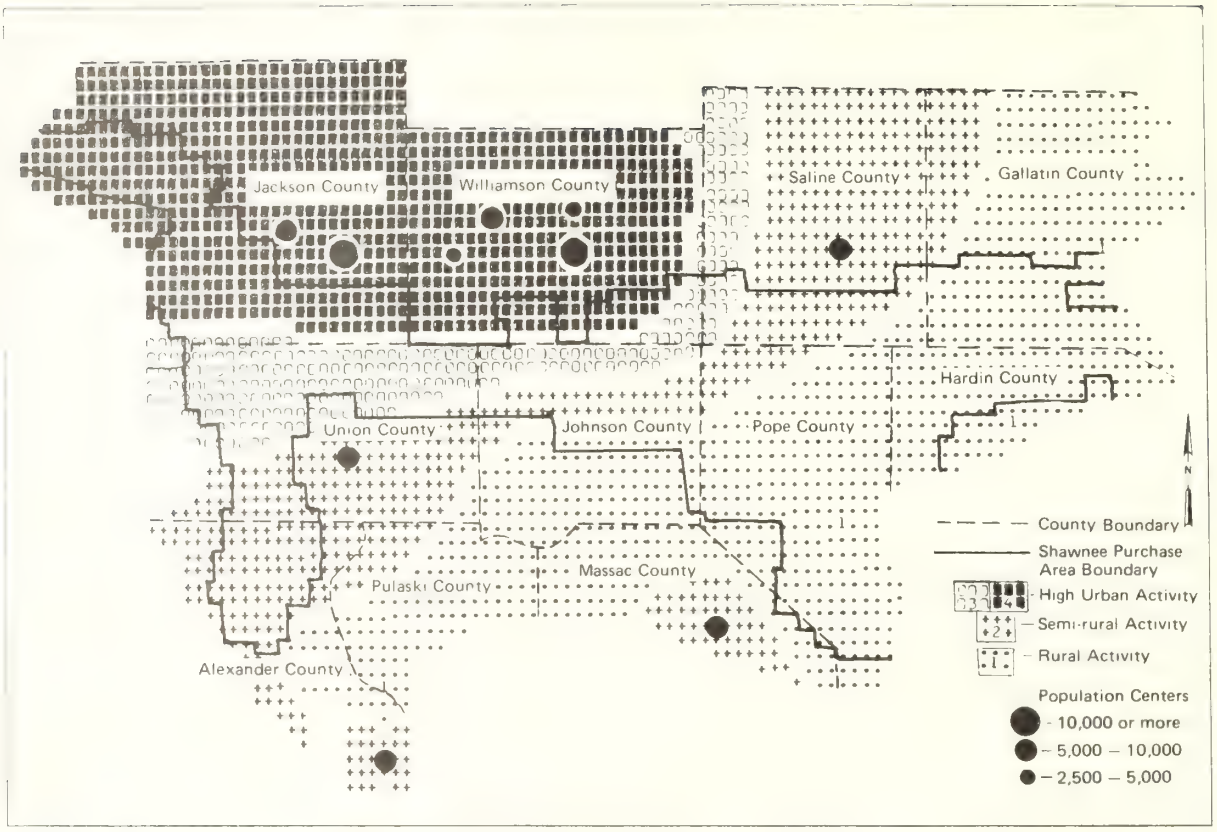

Figure 3. — *Factor one – urban economic activity.*

urbanization present in a particular county is the overriding characteristic in determining levels of economic activity. This factor accounts for a large portion of the differences in economic welfare and opportunity among the counties in association with a degree of urbanization. Thus, this factor is the most important consideration in determining whether a county is a viable economic unit. It follows then, that because there is very low interaction between the National Forest and this factor, the presence of the National Forest is not a major variable influencing levels of economic activity in various counties in the region.

Factor Two: Individual Income

This factor is directly related to individual welfare in the study region. It loads most highly on mean income and percentage of the county population below the poverty level. The factor does not load importantly on any other variables, including presence of the National Forest. This indicates that the National Forest is generally a neutral variable in determing individual economic welfare in the region, as measured by income and poverty level.

The factor map (fig. 4) was constructed by placing a factor score at the point of highest population in the county. The map clearly delineates two pockets of poverty in the region. One lies within the Shawnee National Forest boundaries in Pope and Hardin Counties. A second more extensive area is centered south of the Forest in Alexander and Pulaski Counties. The marked areas of high and intermediate income are much larger than the preceding factor would lead one to believe. This probably reflects the ability in some of the more rural counties to commute to the urbanized areas for employment.

The extensive pocket of poverty in Alexander and Pulaski Counties appears to be statistically related to the presence of a large black population in these counties. Blacks make up 28 percent of the population in Alexander County and 32 percent in Pulaski County. Appoximately 60 percent of the

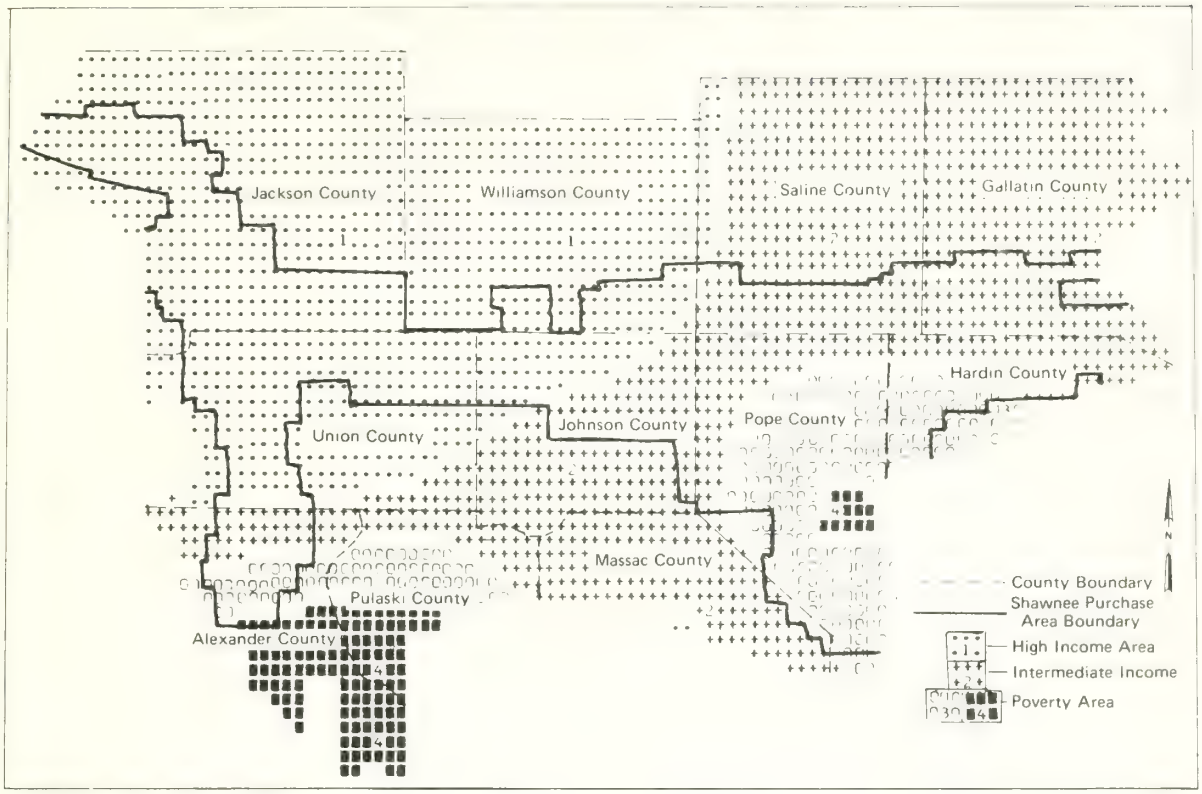

Figure 4. — *Factor two – individual income.*

blacks in these two counties had incomes below the poverty level according to the 1970 census. While the reasons for these conditions appear to be outside the scope of this study, they can generally be attributed to a changing economy, lack of opportunity, probable discrimination, and other common causes of rural poverty. The problem of black poverty in southern Illinois is also related to some extent to a larger regional problem that extends beyond the boundaries of the study area. This area includes northwestern Kentucky, western Tennessee, and especially the "boot-heel" area of southeastern Missouri directly across the Mississippi River from the counties in question. Southeastern Missouri in particular has been well documented as having some of the worst rural, black poverty in the nation. The point is, this particular situation has widespread causes that are not particularly related to the presence of the National Forest.

Explaining the poverty area in Pope and Hardin Counties is more difficult. Two conditions appear to contribute highly to this situation: remoteness from regional employment centers and extremely marginal agriculture. The fact that large amounts of National Forest also exist in these counties appears to be an outgrowth of these same economic conditions rather than the cause of them. In conjunction with the previous factor description, a pattern emerges which points to an apparent relation between the density of National Forest ownership and a marginal economy. This appears to be a coincidental structural relation.

Thus, in simple terms it appears that this factor and the previous one point to the notion that the presence of a low level of economic welfare with a high density of National Forest ownership may arise out of common conditions, rather than one being the cause of the other.

Factor Three: Density of National Forest Ownership

Factor three has a high positive loading on the percentage of county area in National Forest, a low loading on county size, and negligible association with the remaining variables. This factor pattern to a large extent confirms the previous

suggestion that the Shawnee National Forest is not the cause of low levels of eonomic welfare in southern Illinois. The factor loadings on each variable are tabulated below to emphasize the lack of importance of most of them to this factor.

Variable		Loadings of factor three, density of National Forest ownership
V_1	County population, 1970	−0.052
V_2	Mean county income, 1970	.021
V_6	Percentage of the population below the U.S. poverty level, 1970.	.045
V_9	County area in acres	.343
V_{11}	Number of acres classed as tillable in the county, 1969.	−.112
V_{17}	Number of manufacturing plants employing more than 20 workers, 1972.	−.041
V_{19}	Median school years completed, 1970.	−.137
V_{21}	Total county tax revenues, 1972	−.110
V_{23}	Percentage of county area in National Forest.	.851
V_{26}	Total per capita retail sales, 1971	.024

The loadings of county area and percentage of National Forest by county represent a composite variable or factor that we have called "density of National Forest ownership". It measures both the amount of National Forest and also the proportion of National Forest by counties, primarily the latter. These two variables are not correlated in a simple sense, as table 1 shows. Percentage of National Forest in counties may be high, medium or low, irrespective of county size, but on the average, county size reflects amount or area of National Forest. Hence, the larger the county, on the average, the larger is the area of National Forest (not the percentage). So both the amount of National Forest and its proportion by counties are reflected by the factor, which is a comprehensive measure of National Forest. This type of result is one of the useful features of factor analysis.

The remaining variables, which in one way or another reflect economic characteristics, show negligible association with the presence of National Forest.

To generate the factor map (fig. 5), factor scores for each county were placed in the area of most extensive National Forest ownership. Because of the mapping program used, densities may spill over into areas outside the purchase area boundaries. The map indicates more than just where National Forest ownership is most extensive; it also indicates to a certain extent the suitability of certain areas for extensive types of use such as National Forest, due to the effects of the other variables and their compatibility with such use. Darker areas represent greater intensity of this factor.

Factor Four: Educational Opportunity

This factor's highest loading is on education. It has moderately high positive loadings on population, tax revenue, and to a lesser degree size of county, and has a high positive correlation with factor one, urban economic activity.

The map (fig. 6) was generated by placing factor scores in the population center in each county. The darker areas (Jackson and Williamson Counties) are the counties having high educational levels and strong educational opportunities. These counties have relatively high levels of economic activity and are generally the most capable of supporting county government, supplying services, and providing educational opportunity. Educational levels and opportunity drop sharply in the remaining counties. Saline and Pope Counties have moderate educational opportunities, with the remaining counties primarily at the bottom of the scale.

Somewhat surprisingly, Pope County ranks above its counterparts in educational opportunity. It might be expected that low population density and limited economic activity in Pope County would work to the detriment of education. However, the fact that over one-third of the county is in National Forest ownership may mean that more money is available for education, since the county in effect has a smaller land area over which wealth and government services must be extended. In a sense, the National Forest may have zoned Pope County to its own benefit.

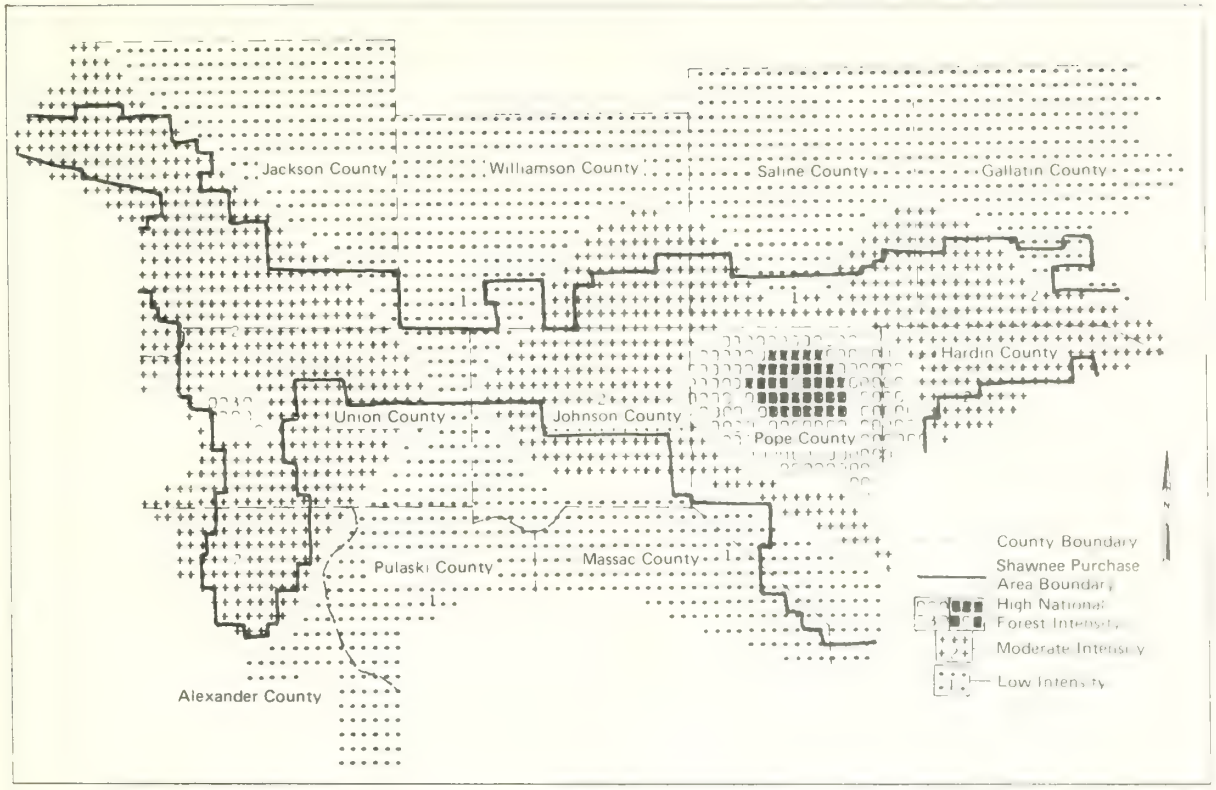

Figure 5. — *Factor three – density of national forest ownership.*

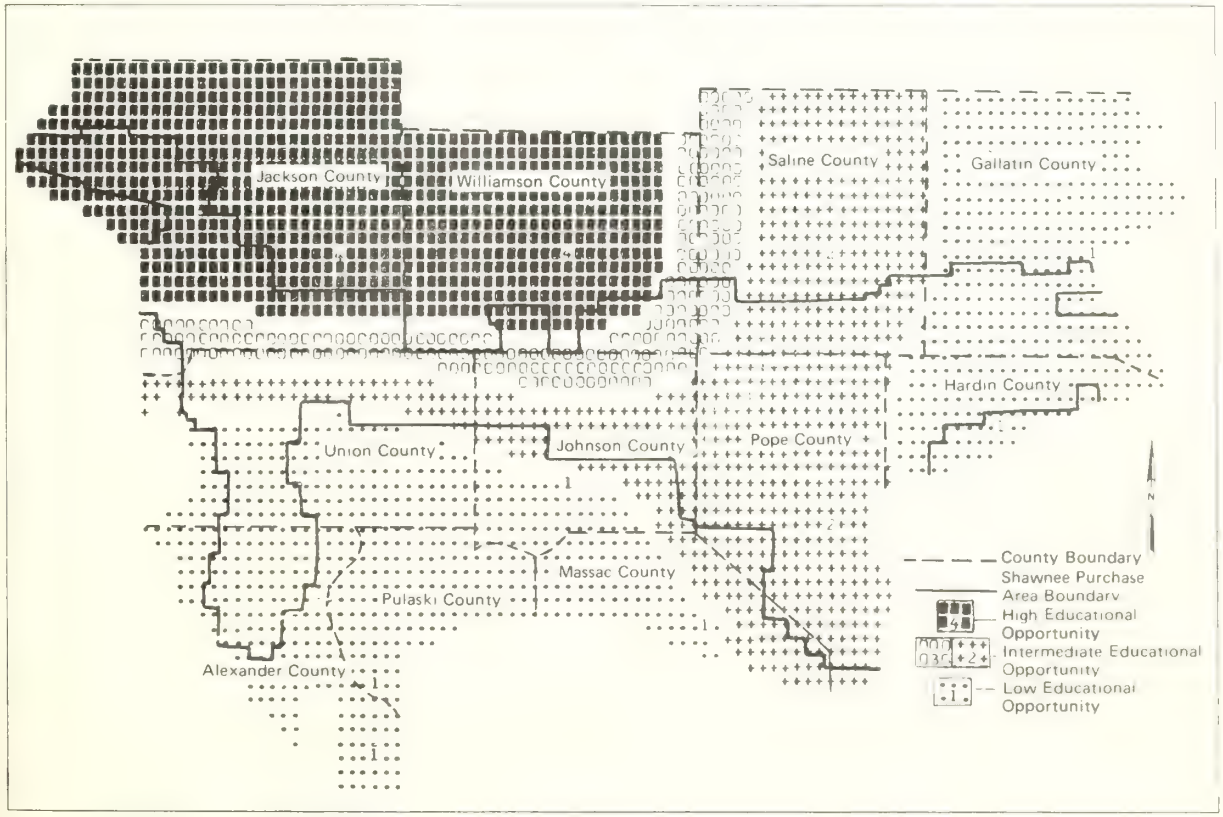

Figure 6. — *Factor four – educational opportunity.*

Factor Five: Agricultural Intensity

This factor loads highly on tillable acreage and moderately on county size. The loadings on the remaining variables are neutral and not significant, including the National Forest variable. This factor reflects primarily the great disparity in agricultural opportunity in the study region, due primarily to highly variable soil and topography. The agricultural variable used was the number of tillable acres in each county; therefore, the results favor row cropping over other types of agriculture, such as fruit and livestock, which may be important in certain localities. However, this variable was chosen because it best reflects the direct productivity of soil and topography.

As seen on the map (fig. 7), only Jackson County has a large potential for highly intensive agriculture. Intermediate potential exists in Union, Saline, and Gallatin Counties, with the remaining counties possessing only marginal agricultural resources. It should be remembered that this map represents the strength of the relation of the factor to each county. Because of the nature of the mapping process, the distribution at each level of intensity of agriculture does not necessarily represent where agriculture *in general* actually takes place. However, a comparison of the factor map with a soil map (fig. 8) confirms the positive relation between large areas of productive soil in particular counties and this factor.

The low negative loading of the National Forest variable suggests an inverse relation to intensive agriculture. This is not surprising, because of the basic incompatibility of extensive land use with more intensive agriculture.

Factor Correlations

Now that each factor has been defined and explained, it is useful to examine the relations among factors, and the linkages with individual variables. Table 3 shows the correlations among factors. Because these factor correlations are computed through the factor scores (the scores of factors on observations, which in this case are counties), the correlations also reflect spatial associations.

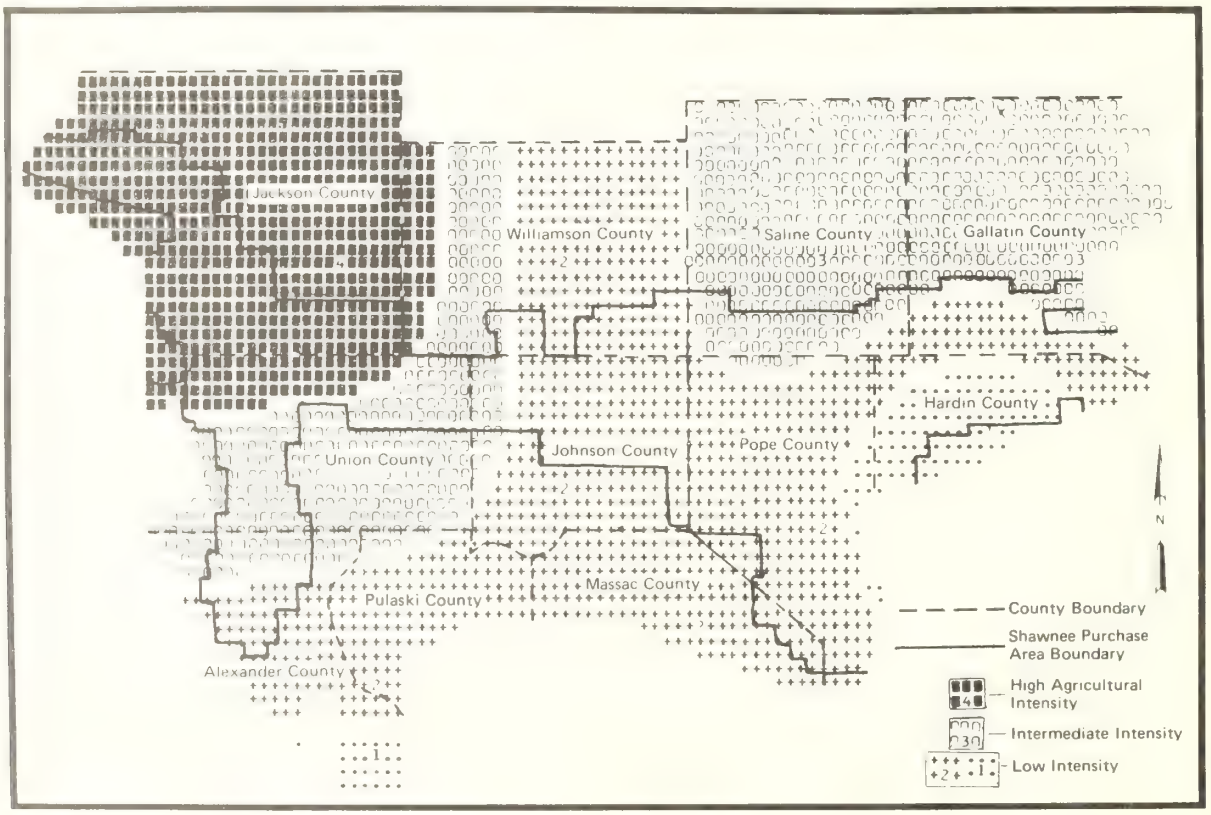

Figure 7. — *Factor five – agricultural intensity.*

Table 3. — *Oblique factor intercorrelations*[1]

	Urban economic activity	Individual income	Density of National Forest ownership	Educational opportunity	Intensive agriculture
	F_1	F_2	F_3	F_4	F_5
F_1	1.0	0.57	−0.24	−0.76	0.44
F_2	−.57	1.0	.19	−.46	−.62
F_3	−.24	−.19	1.0	−.02	−.13
F_4	.76	.46	−.02	1.0	−.39
F_5	.44	.62	−.13	−.39	1.0

[1]These are moderate correlations among factors because the program used was a particular oblimin rotation, which permits oblique factors (interdependent) but does not tend to overlap the factors.

Perhaps most important is the relation of factor three to the others; however, the reader may wish to scan the others for consistency. Factor three (density of National Forest ownership) has the lowest correlations with every other factor, while factor one, urban economic activity, shows a strong relation to the other factors. Factors two and four are primarily direct measures of individual welfare, while factors one and five represent economic activity from which economic welfare inferences may be drawn.

The low correlations between factor three and the others indicates, as the preceding analysis did, that the National Forest has very little if any interaction with economic activity in the region. In areas of the region where a high density of public land coincides with low economic activity, it is due primarily to common causes such as poor farmland, lack of urban economic activity, or other conditions which produce low-intensity land use. These conditions result in land predisposed toward extensive use such as National Forest. Factor one largely depicts individual welfare (measured by income and education) and where wealth is concentrated. This in turn supports viable county government and educational opportunity through a large tax base. This factor in association with factor five (agriculture) determines almost completely the economic well-being of a particular county.

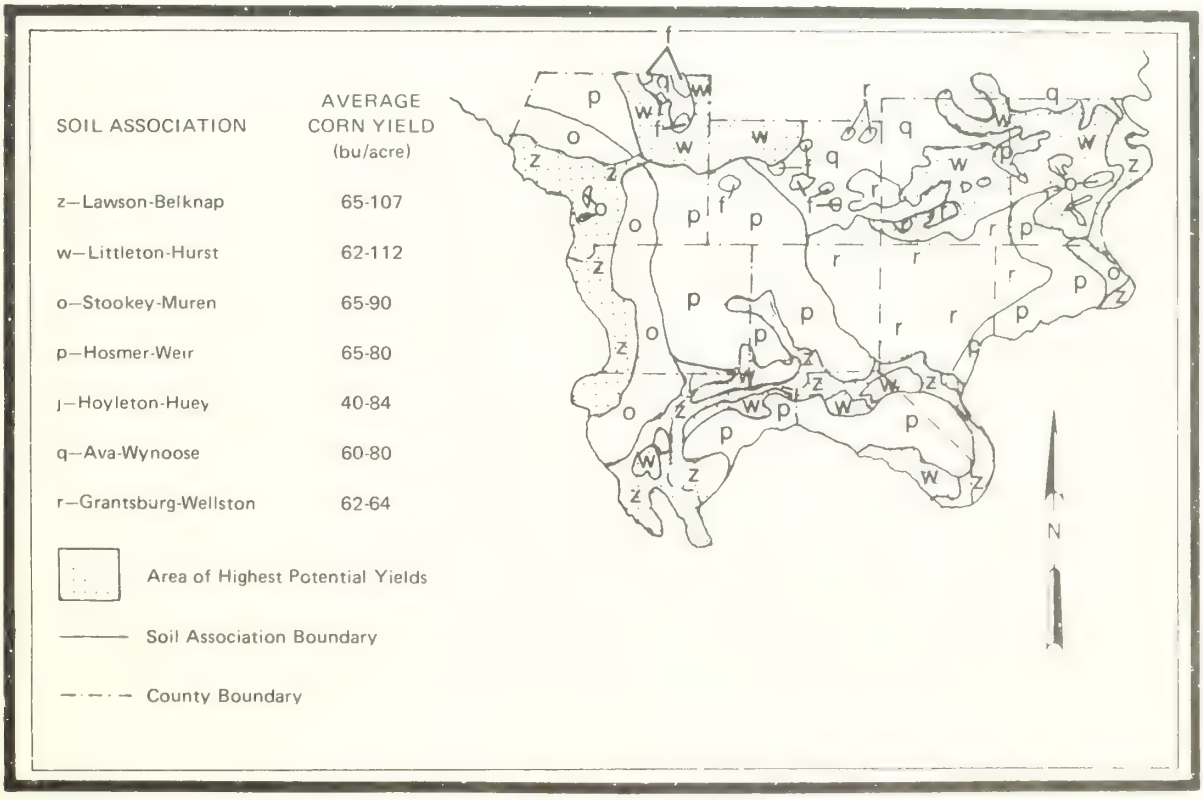

Figure 8. — *Major soil associations in the study region (Anonymous 1967).*

Figure 9 shows the linkages of various factors to individual variables (> 0.40 loading). Positive and negative signs indicate the nature of the relation between variable and factor. The most important observation that emerges from this diagram is the relative independence of the National Forest factor from the web of interrelations among the other factors.

EFFECT OF THE SHAWNEE NATIONAL FOREST ON COUNTY REVENUES

One of the chief criticisms leveled against the Forest Service in southern Illinois (and elsewhere) is that the tax immunity of Federal land causes substantial property tax losses to counties. To determine the impact of the Shawnee National Forest on county revenues, we used a stratified comparison of several counties based on the most recent year for which data could be assembled.[3]

[3]*Data taken from "National Forest Contributions to Local Governments, 1952", and "National Forest Contributions to Local Governments, 1962". These USDA Forest Service reports were national in scope and involved sampling of counties throughout the United States. Jackson and Pope Counties were the sample counties for Illinois (and the Shawnee National Forest) in both reports.*

Five counties were selected on the basis of two criteria: (1) degree of urban activity as identified by factor one in the preceding analysis, and (2) degree of influence of the National Forest as indicated by the percentage of county area in National Forest. Counties having more than 10 percent of their area in National Forest were considered high-intensity National Forest counties, while those having less than 10 percent were considered low-intensity. Selection of the latter criterion was based on a 10.8 percent average county area in National Forest for the entire study period.

The five Counties selected were Johnson, Pope, Massac, Union, and Jackson. Johnson and Pope Counties may be classed as rural counties according to the prior analysis. Johnson is a low-intensity National Forest county with 7.9 percent of its area in national forest (1972), and Pope is a high-intensity county with 34.6 percent of its area in that use. Massac and Union Counties are semi-rural counties with 1.9 and 13.2 percent of their areas in national forest, respectively. The final County, Jackson, is an urban county with 11.8 percent of its area in national forest, putting it in the high-intensity class. This County was selected for comparison because it indicates, as will be shown later, the degree to which urbanization offsets any large economic impact of the National Forest.

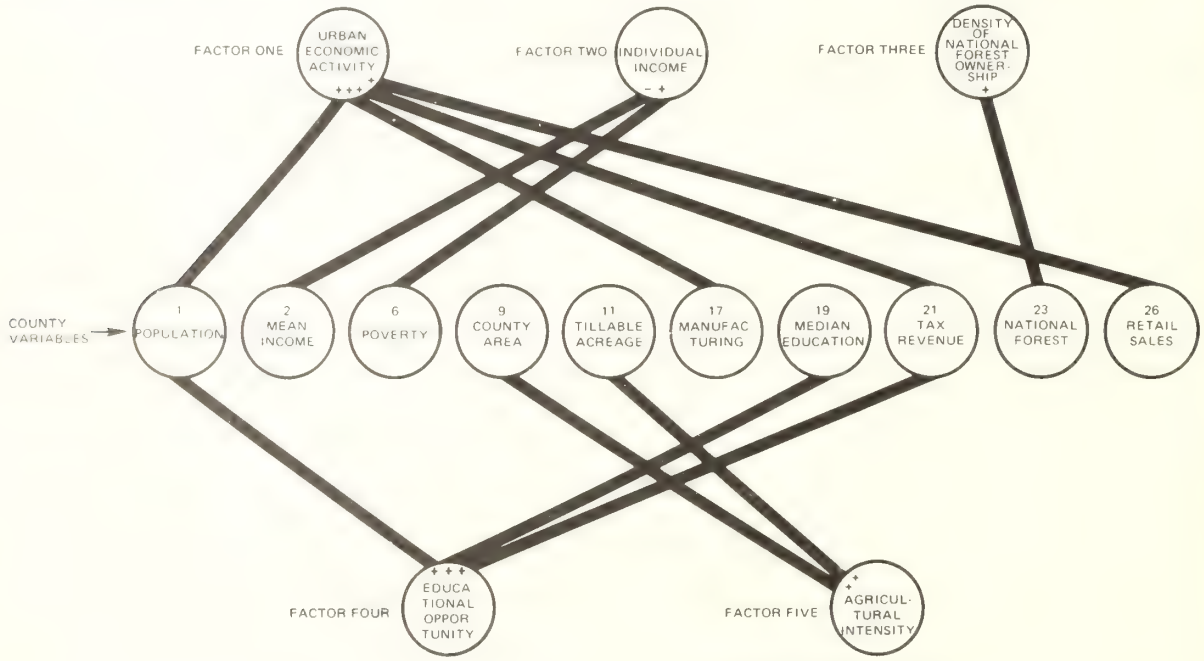

Figure 9. — *Major linkages between factors and variables.*

As a first step, a ratio between average price paid for farmland and average price paid for national forest land was established for the five counties. These data were compiled from 1954-1969 census of agriculture information and from USDA Forest Service records (table 4).

The expected market value of Forest Service land in each county (table 5) was determined by multiplying the average 1972 value per acre of farmland in each county by the ratio. This calculation assumes differences in land values for the same types of land under varying intensities of demand (caused primarily by various levels of population and economic activity in each county). It also makes two other implicit assumptions. The first is that the presence of national forest itself does not significantly affect the prevailing rural land prices. The second is that this current expected market value reflects generally the current value of all national forest land in a particular county.

Under these assumptions, the expected market value of USDA Forest Service land may be used to calculate estimated tax losses. This was done two ways to produce a high and low range of tax loss in each county. The first method used the letter of the law for property tax assessment in Illinois in 1972: 100 percent of "fair cash value", which is defined as 50 percent of the actual market value of such property, "not at forced sale or auction" (Anon. 1972). The second method, which yielded lower figures, was based on a ratio between average market values in table 6 and average dollar assessments per acre from previous USDA Forest Service reports. This ratio was calculated at 41 percent of current market value.

These two assessment ratios were incorporated into a final calculation for each county to estimate the range of tax loss in each case, as follows:

Total National Forest acreage in county (1972)	×	Expected market value	×	One of the two assessment ratios	×	County tax rate (1972)	=	Total tax loss

Total tax loss may be then divided by the national forest acreage to produce the average tax loss per acre (tables 6 and 7).

The highest tax losses per acre occur with increasing urbanization, because increasing population increases the cost of all land and tends to raise tax rates and assessments. However, the impact is greater in rural counties because alternative forms of wealth are largely absent and total revenues are much lower. In the most extreme case, Pope County, little taxable property exists other than land. The factor maps show an overlap of low economic and agricultural activity that contributes to a high dependence on land as the chief source of wealth in this county. As urbanization and economic growth take place, rural land becomes less important in generating tax dollars.

To complete this analysis a comparison must be made between apparent tax losses and revenue-sharing payments and in-kind benefits accruing to the counties. In-kind benefits have in the past been considered to be those costs that would otherwise be borne by the counties. This definition has been broadened somewhat in this analysis to include some costs that the counties might not have been able to bear themselves. However, these costs are direct benefits to the counties and the criterion is that the counties could conceivably have borne them. These in-kind benefits are represented by expenditures in four categories:[4] (1) cooperative

Table 4. — *Ratio of average purchase prices of National Forest land to average farm prices per acre*

Year	(A) Average price per acre paid for Forest Service land	(B) Average price paid for farm land—five sample counties	A/B ratio
1972	$112.90	$262.55	0.43
1969	84.70	228.95	.27
1959	37.52	144.30	.26
1954	11.47	60.37	.19

Table 5. — *Expected market values of National Forest land, 1972*

County	Average farm value per acre, 1972	Ratio for 1972	Expected value per acre of national forest land, 1972
Pope	$205.00	0.43	$ 88.15
Johnson	251.36	.43	108.08
Massac	267.37	.43	114.97
Union	265.24	.43	114.05
Jackson	326.38	.43	140.34

[4]*Source: Forms 6500-90 Geographic Ratio of Federal Outlays, compiled 2/23/74 for fiscal year 1973. These forms depict the funds expended by the Shawnee National Forest according to the county for various types of appropriations.*

Table 6. — *Assessment of National Forest land at 50 percent of expected market value, 1972*

County type	County	National Forest acreage	1972 estimated tax loss	Estimated loss per acre
Rural/high NF	Pope	81,493	$32,326	$0.40
Rural/low NF	Johnson	16,564	5,639	.34
Semi-rural/high NF	Union	33,735	15,582	.46
Semi-rural/low NF	Massac	2,995	1,567	.52
Urban/high NF	Jackson	39,995	22,452	.56

Table 7. — *Assessment of National Forest land at 41 percent of expected market value, 1972*

County type	County	National Forest acreage	1972 estimated tax loss	Estimated loss per acre
Rural/high NF	Pope	81,493	$26,508	$0.32
Rural/low NF	Johnson	16,564	4,624	.27
Semi-rural/high NF	Union	33,735	12,777	.37
Semi-ruralow NF	Massac	2,995	1,285	.42
Urban/high NF	Jackson	39,995	18,410	.46

law enforcement, (2) forest roads and trails, (3) water resource development, and (4) pollution abatement.

These expenditures for the five-county sample were made during fiscal year 1973. This is the same period during which tax monies from 1972 were being expended, and so are comparable on that basis. In addition, revenue-sharing payments made under the Weeks Law of 1911 are shown as direct financial benefits. Table 8 shows a comparison between these benefits and the calculated tax losses.

It is apparent from this table that shared revenues generally amount to less than half of estimated tax losses. However, as past studies have shown (EBS Management Consultants 1968), the addition of in-kind benefits generally tips the balance of benefits positively. The five-county average shows a comfortable $0.42 to $0.50 per acre of net benefits accruing to the counties over and above apparent tax losses. Tax losses of $1.00 per acre (Callahan *et al.* 1974) are not supported by our analysis. On a county-by-county basis, however, a greater pattern of inequity emerges. Massac County shows a negative net benefit (a net loss) of

Table 8. — *Comparison of estimated tax losses and net revenues accruing to counties as a result of National Forest ownership, 1972*

County type	County	Estimated 1972 tax loss per acre (low-high Range)	Weeks Law revenue payment per acre, 1972	In-kind benefits per acre	Net benefits (Col. 2+3 -1)
		1	2	3	4
Rural/high NF	Pope	32-40¢	15.4¢	31.6¢	+7 to 15¢ p/acre
Rural/low NF	Johnson	27-34¢	15.4¢	$1.08	+89 to 96¢
Semi-rural/ high-NF	Union	37-46¢	15.4¢	$1.07	+76 to 85¢
Semi-rural/ low-NF	Massac	42-52¢	15.4¢	.00	−(26.6 to 36.6¢)
Urban/high NF	Jackson	46-56¢	15.4¢	$1.14	+73 to 83¢
Five-county average		37-45¢	15.4¢	$71.6	+42 to 50¢

0.27 to $0.37 per acre. The low national forest creage in this county prevents this from being a erious loss. At its highest range this loss amounts o only 0.001 percent of Massac County's total revnues for 1972. The low margin in Pope County is nore serious. The variability of revenue-sharing ayments in conjuction with variable expenditures on in-kind benefits would certainly make it onceivable that net benefits could at times dip elow zero, lending some support to the notion that ax losses do take place from time to time. However, the magnitude of the losses would be very mall, since some form of revenue sharing always akes place. The sub-marginal nature of Pope County's economy (as shown by the factor analyis) certainly indicates that every effort should be nade to avoid further stress to its economy. But laims of excessive tax losses on a regular basis ppear to be unfounded. The remaining three ounties show substantial positive net benefits beause of high expenditures by the Forest Service n in-kind benefits.

CONCLUSIONS AND RECOMMENDATIONS

To clarify the conclusions that can be drawn rom the preceding analysis, it is necessary to retate the hypotheses that were tested:

1. The socioeconomic structure of southern Illinois is sufficiently homogeneous to be analyzed systematically.
2. The Shawnee National Forest has a significant effect on the socioeconomic structure of the region.
3. The Shawnee National Forest has a negative effect on individual welfare, regional economic welfare, and local governmental welfare.

The results of the factor analysis demonstrate hat the first hypothesis can be accepted. The ocioeconomic structure of the region can be rganized into a model of major socioeconomic reations or dimensions. When these are put into isual form they help to explain and simplify the xisting socioeconomic structure.

The analysis refutes the second hypothesis, in hat no significant relations, either positive or egative, were found that would suggest the Shawnee National Forest has any major effect on the socioeconomic structure of the region.

Hypothesis three is dependent on the outcome stated above, and is therefore also negative.

THE RELATION OF THE SHAWNEE NATIONAL FOREST TO THE ECONOMY OF SOUTHERN ILLINOIS

Two major conclusions may be drawn from the results stated above. First and most important, the evidence does not support the contention that the Shawnee National Forest has a negative impact on the economy of southern Illinois. Second, no evidence was found to support the assertion that large revenue losses to county government take place as a result of the tax immunity of Forest Service land. The results of the factor analysis further demonstrate that the association of large amounts of national forest with low levels of economic activity in particular areas generally arise out of common economic conditions. The national forest has a structural relation to marginal economies. This relation appears to be based on the fact that in less active economies, land use tends to be less intensive. This results in cheap land predisposed towards extensive use such as national forest. Thus, low levels of public and private economic welfare are not caused by the national forest.

Large areas of southern Illinois have throughout their history been considered to be economically marginal (Soady 1965). This was the situation when the Forest Service entered the region in 1933, and it has changed only moderately since that time. Soady (1965) and Callahan *et al.* (1974) suggest that the Forest Service entered the region for two purposes: to stabilize the management of land that had been severely exploited and misused for most of its history, and to stimulate the economy of a depressed region and stabilize land tenure and property tax forfeiture, which was rampant in southern Illinois during the Depression. The first purpose has largely been accomplished. The indications of this study are that the second has met with only limited success.

At present the Forest Service is only a neutral factor in the economy of the region. There has been little change in the relative standing of individual

counties in regard to wealth or economic viability since the Forest Service entered in 1933. Figure 10 shows a graph of total assessed valuations of five sample counties from 1913 through 1972. Counties that had the lowest values in 1913 have continued in that trend, with the exception of Massac. The difference in wealth between the economically viable counties and the marginal ones has grown greater in each year. Extreme disparity in urban economic activity, job opportunities, agricultural opportunity, and distribution of resources remain the overriding factors in determining economic well-being in southern Illinois. It can be stated with some certainty that in many ways the national forest has been a stabilizing force in the region. Certainly the contribution of the Shawnee National Forest toward establishment of productive land use and in providing recreation benefits, water resource development, and fish and wildlife management have immensely improved the environment of the region. However, the net effect of the forest on economic development, so sorely needed, has been only moderate at best.

The coincidence of Forest Service land with marginal economies in particular areas has hurt the public image of the Forest Service somewhat.

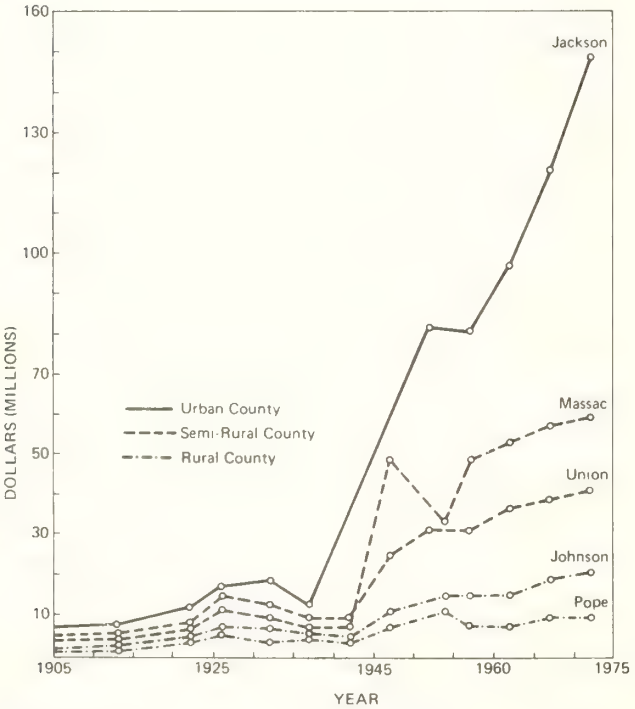

Figure 10. — *Total equalized assessed valuations of the five sample counties.*

However, the extensive land management practiced by the Forest Service makes this type of relation almost inevitable. This relation, more than anything else, probably leads the public to the conclusion that the National Forest somehow hurts the economy of southern Illinois. However, reviewing the history of the region and systematically analyzing its present condition leads one to the conclusion that the economy of the region would be no better off if the Forest were not present, and in some ways might be worse off.

The location of the Forest in relation to areas of low economic activity is inextricably woven into the problem of revenue sharing and property taxes. Lack of urban economic activity has been identified as the overriding factor in determining the viability of county government. Pope County, which has been the focal point for the tax immunity controversy in the region, reflects this problem in its most extreme state. It is evident that when significant or even moderate amounts of alternative wealth exist in a particular county, large amounts of public land make little difference to the viability of county government. The best examples of this are Jackson, Union, and Williamson Counties. The high correlation shown between urban economic activity and taxes make this factor the overriding predictor of local government welfare. Certainly the low level of individual and public welfare found in Pulaski County, which lies completely outside the purchase area, lends much credence to this explanation.

If the present revenue-sharing and in-kind benefit system has any problem at all, it lies in its inherent inflexibility. Shared revenue has been shown to amount to less than half of potential taxes in all cases for which estimates were made. These funds represent the only contribution to local government made by the Forest Service over which the State and County have any degree of control. Even this flexibility was, in the past, hampered to a large degree by the practice of "earmarking" funds for specific uses (EBS Management Consultant 1968)[5]. The high variability of expenditures that result in in-kind benefits to the

[5]*The report states (p. 67) that only 1.5 percent of section 10 land payments (which include Forest Service land) were shared without Federal restriction on their use. In 1966, 98 percent of such funds were ear-marked for roads and schools.*

counties further complicate the problem, since the management policies of the Forest dictate where those funds must be expended.

Expenditures per capita on social services have risen very sharply in the more marginal counties of the study region. This is illustrated by comparing low-income Pope County with Jackson County (fig. 11). In spite of the generally positive margin of benefits to the study region resulting from the Forest Service presence, the inflexibility of the revenue-sharing system makes problems such as this very difficult for local government to deal with.

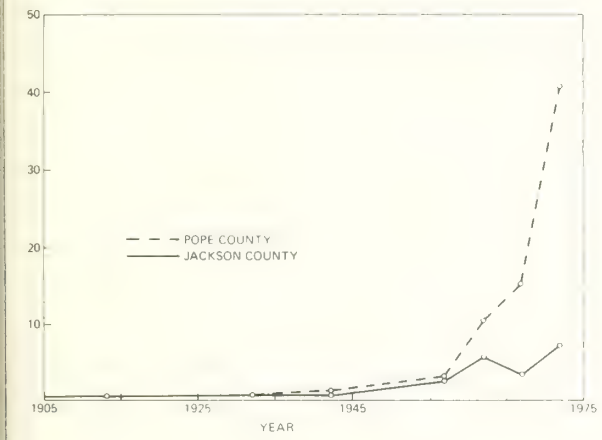

Figure 11. — *Expenditures on social services (U.S. Census of Government and county records).*

THE ROLE OF THE FOREST SERVICE IN REGIONAL ECONOMIC DEVELOPMENT

The Forest Service is increasingly being forced by legislative and public pressure to act as a funnel for aid to rural, economically depressed regions. Federal water resource projects have already gone through this evolution (Haveman 1965). The present system of revenue-sharing is based on the productivity of land in each management unit. Legislative proposals which seek to replace this system with minimum payments or some other system of payments in lieu of taxes will inevitably move the Forest Service in the direction of becoming a local agent of the Federal government for promoting regional economic development, perhaps at the expense of more efficient means of accomplishing the same end. Certainly a movement in this direction would require drastic changes in the objectives of the Forest Service.

A real question remains as to whether the Forest Service, whose activity is to produce public goods for the collective welfare of the Nation, should be placed in a position where it is held accountable to regional welfare and subjected to constant scrutiny in this regard. This type of accountability has led inevitably to a pressure within the Service to behave like a private corporation in generating revenue. On many National Forests such as the Shawnee, conditions are not conducive to high revenue generating activities. However, the furor over apparent harm to the local economy as a result of the low revenues often obscures the benefits of environmental enhancement, recreation, wildlife, and water production, which are outside of the normal market structure.

The drift of current legislation and public sentiment seems to be toward a more active role by the Forest Service in regional economic development and local government support. Perhaps the time has come for the Forest Service to develop one of three policies. It may take the initiative and attempt to structure this trend in a manner that best fits its existing goals and objectives of enhancing national welfare — a middle course. Or it may restructure its goals, policies, and administration to actively embrace coordinated regional development and local support. Or it may wish to carefully reshape its policy to avoid more extended involvement in regional development and monetary transfers to various local governments.

In any event, it seems fairly certain that some policy research planning relative to these alternatives is desirable if the Forest Service is to be prepared to best serve the national interest.

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APPENDIX A

COMPARATIVE COUNTY DATA

Complete Variable List

Variable Number

*1.) Total county population, 1970.[1]

*2.) Mean county income, 1970.[1]

3.) County worker to nonworker ratio, 1970.[1]

4.) Percentage of the county population classified as nonwhite, 1970.[1]

5.) Percentage of the county work force employed outside the county, 1970.[1]

*6.) Percentage of the county population below the 1970 U.S. poverty level.[1]

7.) Percentage of the county work force employed in one of seven occupational categories:[1]
   a. Agriculture
   b. Mining
   c. Construction
   d. Manufacturing
   e. Transportation, Utilities
   f. Retail and Wholesale Sales
   g. Services

8.) County age distribution.[1]

*9.) County area in acres.[1]

10.) Number of urban places exceeding 2,500 in population in the county.[1]

*11.) Number of tillable acres in the county, 1969.[2]

12.) Number of operating mines in the county, 1972.[3]

13.) Number of reservoirs exceeding 500 acres in size in the county.[5]

14.) Number of interstate highway exchanges in the county.[5]

15.) Percentage of the county work force employed in state and federal jobs.[1]

16.) Deleted and replaced by variable 26.

*17.) Number of manufacturing plants employing more than 20 persons in the county, 1972.[3]

18.) Township or county commission government.[4]

*19.) Median school years completed by the county population, 1970.[1]

20.) Total school enrollment in the county, 1972.[4]

*21.) Total county tax revenues, 1972.[4]

22.) Number of county government employees.[4]

*23.) Percentage of the county area in National Forest.[5]

24.) Number of National Forest recreation sites in the county.[5]

25.) National Forest revenue sharing payment, 1974.[5]

*26.) Per capita retail sales in the county, 1972.[6]

Sources of Data

1. U.S. Census of Population, 1970
2. U.S. Census of Agriculture, 1969
3. U.S. Census of Manufacturing, 1972
4. U.S. Census of Government, 1972
5. U.S. Forest Service literature and maps
6. U.S. Census of Business, 1972

*Variables used in the factor analysis.

County Data Observations

Alexander		Gallatin		Hardin	
Variable Number	Observation	Variable Number	Observation	Variable Number	Observation
1	12,015	1	7,418	1	4,914
2	6,738	2	7,389	2	6,908
3	.31	3	.31	3	.31
4	28.1	4	NA	4	NA
5	13.2	5	15.6	5	9.6
6	31.2	6	16.3	6	23.7
7a	5.6	7a	15.2	7a	2.7
b	.82	b	11.2	b	25.0
c	5.7	c	6.2	c	6.2
d	15.9	d	17.6	d	9.5
e	11.0	e	3.6	e	8.4
f	23.9	f	18.2	f	16.0
g	37.1	g	28.2	g	30.3
8a	13.8	8a	15.8	8a	14.3
b	6.1	b	5.1	b	5.1
c	12.1	c	9.1	c	11.0
d	7.6	d	11.3	d	7.4
e	17.5	e	22.0	e	20.9
f	25.4	f	23.0	f	25.7
g	17.5	g	13.7	g	15.6
9	143,360	9	209,920	9	117,119
10	1	10	0	10	0
11	62,738	11	135,776	11	31,822
12	2	12	44	12	14
13	1	13	0	13	0
14	0	14	0	14	0
15	16.3	15	14.6	15	31.9
16	deleted	16	deleted	16	deleted
17	7	17	4	17	1
18	no	18	yes	18	no
19	9.4	19	9.2	19	8.8
20	2,838	20	1,725	20	1,066
21	394,000	21	218,000	21	144,000
22	NA	22	52	22	27
23	18.7	23	5.1	23	19.9
24	1	24	2	24	4
25	2,551.74	25	1,014.94	25	2,209.76
26	2,179	26	1,328	26	1,106

Jackson		Johnson		Massac	
Variable Number	Observation	Variable Number	Observation	Variable Number	Observation
1	55,008	1	7,550	1	13,889
2	9,196	2	7,372	2	7,770
3	.36	3	.32	3	.33
4	7.2	4	NA	4	6.8
5	8.4	5	25.6	5	18.0
6	14.1	6	17.4	6	17.6
7a	3.7	7a	10.1	7a	8.7
b	.75	b	2.7	b	.54
c	5.4	c	13.0	c	7.7
d	12.0	d	14.4	d	22.6
e	5.9	e	8.3	e	11.6
f	17.7	f	17.1	f	19.8
g	54.5	g	34.3	g	29.2
8a	12.0	8a	11.8	8a	13.6
b	4.0	b	5.8	b	5.9
c	7.9	c	10.5	c	10.6
d	32.5	d	12.5	d	20.9
e	19.0	e	21.4	e	22.0
f	15.5	f	21.8	f	13.1
g	9.1	g	16.2	g	13.9
9	384,815	9	220,626	9	157,440
10	2	10	0	10	1
11	164,546	11	78,094	11	80,862
12	3	12	0	12	3
13	2	13	1	13	1
14	0	14	4	14	1
15	36.9	15	29.3	15	14.6
16	deleted	16	deleted	16	deleted
17	11	17	1	17	5
18	yes	18	no	18	no
19	12.1	19	8.8	19	9.9
20	9,040	20	768	20	3,577
21	1,194,000	21	90,000	21	538,000
22	NA	22	NA	22	56
23	11.8	23	34.6	23	1.9
24	6	24	4	24	0
25	3,913.51	25	7,956.84	25	284.59
26	2,133	26	1,176	26	1,636

Pope		Pulaski		Saline	
Variable Number	Observation	Variable Number	Observation	Variable Number	Observation
1	3,857	1	8,741	1	25,721
2	6,248	2	5,963	2	7,778
3	.25	3	.29	3	.32
4	NA	4	32.0	4	2.7
5	33.3	5	27.4	5	15.7
6	29.3	6	35.7	6	19.3
7a	13.9	7a	12.1	7a	4.2
b	5.7	b	2.7	b	13.5
c	14.9	c	5.3	c	7.3
d	11.6	d	17.4	d	9.1
e	6.0	e	11.7	e	7.4
f	12.6	f	17.2	f	21.5
g	35.3	g	33.6	g	37.1
8a	11.1	8a	14.6	8a	13.0
b	5.7	b	6.6	b	4.8
c	13.4	c	13.8	c	10.0
d	9.0	d	7.6	d	8.3
e	17.1	e	16.9	e	20.4
f	25.7	f	23.4	f	24.9
g	18.0	g	17.1	g	18.6
9	242,080	9	130,560	9	245,759
10	0	10	0	10	2
11	56,828	11	68,908	11	124,872
12	2	12	0	12	33
13	0	13	0	13	0
14	0	14	2	14	0
15	26.8	15	19.9	15	18.3
16	deleted	16	deleted	16	deleted
17	0	17	3	17	4
18	no	18	no	18	yes
19	8.8	19	9.0	19	9.4
20	768	20	2,279	20	4,944
21	90,000	21	180,000	21	518,000
22	NA	22	46	22	35
23	34.6	23	0	23	5.2
24	4	24	0	24	0
25	7,956.84	25	0	25	1,214.49
26	1,176	26	956	26	2,121

Union

Variable Number	Observation
1	16,071
2	8,322
3	.36
4	NA
5	15.1
6	16.2
7a	10.2
b	.90
c	8.9
d	18.2
e	6.8
f	16.3
g	38.7
8a	12.9
b	4.6
c	9.7
d	8.5
e	21.3
f	26.2
g	16.8
9	264,788
10	1
11	103,694
12	2
13	0
14	3
15	28.0
16	deleted
17	7
18	no
19	9.1
20	3,088
21	337,000
22	60
23	13.2
24	5
25	3,327.98
26	1,575

Williamson

Variable Number	Observation
1	49,021
2	8,351
3	.35
4	1.6
5	21.0
6	14.1
7a	1.0
b	7.0
c	7.6
d	21.9
e	7.4
f	20.3
g	33.9
8a	14.2
b	5.5
c	10.2
d	10.0
e	22.8
f	23.1
g	14.2
9	282,228
10	4
11	68,616
12	16
13	4
14	4
15	19.2
16	deleted
17	13
18	no
19	11.3
20	10,600
21	1,396,000
22	107
23	.12
24	0
25	30.89
26	2,301

APPENDIX B

STATISTICAL ANALYSIS USED IN THE STUDY

Spearman Rank Correlation and Partial Correlation Analysis

Once initial visual and graphic analysis had been completed on the county data, 17 variables were chosen to be used in Spearman correlation analysis. Spearman correlation is a nonparametric technique that correlates the ranks of observation on each variable against their rank on other variables. Spearman correlation has a high power efficiency (0.91) to standard Pearson correlation and is an effective substitute where the number of observations on each variable is small. It is based on the formula (Siegel 1956):

$$R_s = 1 - 6^{d2}(n^3 - n)$$

where n is the number of observations and the d's are the differences between ranks for each observation measured on variables X and Y.

A correction factor must be used to remove th effect of ties in the rankings. The formula whe corrected for ties is as follows:

$$r_s = \frac{\left(\frac{n^3-n}{12} - \Sigma T_x\right) + \left(\frac{n^3-n}{12} - \Sigma T_y\right) - \Sigma d^2}{\sqrt[2]{\left(\frac{n^3-n}{12} - \Sigma T_x\right)\left(\frac{n^3-n}{12} - \Sigma T_y\right)}}$$

where T is the number of ties in each ranking. Th results of this analysis are presented on the ne page (table 1).

Eight of the variables listed in table 1 wer eliminated for use in the factor analysis (See Ap pendix A for complete variable list). Variables 20, 24, and 25 were found to be interchangeab measures or functions of other variables throug partial correlation analysis. Variables 5, 12, ar 15 had comparatively low correlations with th remaining variables and so served little usef function in seeking a systematic construct. Va able 16 was replaced by variable 26 because th latter was thought to be a better measure of th same attribute.

Table 1. *Spearman Rank Intercorrelation matrix of selected variables*

	V_1	V_2	V_3	V_5	V_6	V_9	V_{11}	V_{12}	V_{15}	V_{16}	V_{17}	V_{19}	V_{20}	V_{21}	V_{23}	V_{24}
V_1	1.0															
V_2	.81	1.0														
V_3	.82	.93	1.0													
V_5	−.33	−.44	−.43	1.0												
V_6	−.58	−.91	−.83	.31	1.0											
V_9	.66	.79	.68	−.04	−.77	1.0										
V_{11}	.55	.64	.56	−.28	−.58	.52	1.0									
V_{12}	.21	.50	.20	−.37	−.40	.20	.31	1.0								
V_{15}	.01	.11	.20	−.21	−.19	.24	−.11	−.36	1.0							
V_{16}	.34	.30	.19	−.07	−.22	.21	.50	.40	−.59	1.0						
V_{17}	.86	.74	.74	−.46	−.61	.53	.41	.29	−.17	.33	1.0					
V_{19}	.77	.71	.72	−.19	−.64	.54	.51	.19	−.10	.42	.71	1.0				
V_{20}	.97	.79	.76	−.27	−.56	.60	.51	.35	−.17	.39	88	.78	1.0			
V_{21}	.90	.76	.71	−.38	−.54	.49	.45	.47	−.27	.39	.91	.78	.96	1.0		
V_{23}	−.39	−.20	−.18	.03	−.37	−.15	−.47	−.15	−.45	−.35	−.31	−.42	−.50	−.26	1.0	

Other variables that do not appear in the Spearman correlation were used only as informational variables for comparative analysis and in most cases wer suitable for meaningful statistical analysis. (See Appendix A).

Factor Analysis

The 10 variables selected in the above analysis were next analyzed using a Rao's Canonical factor analysis. The Canonical factor analysis model is based on the Maximum Likelihood Factor Model developed by Lawley (1940). Canonical factor analysis follows the common factor model in that it attempts to account for common variance among variables. Unlike common factor analysis, which determines common factors by factoring the correlation matrix with estimates of the communities in the diagonal, canonical factor analysis determines the common factor estimates (loadings) which have the highest canonical correlation with the variables. Harris (1962) says that if a population of cases is involved or may be assumed, significance tests need not be applied. The communality value will be the squared multiple correlation for each variable and the appropriate number of factors will be those with eigen values greater or equal to 1. This was the assumption made in this analysis and final factor selection was made on that basis.

Canonical factor analysis rescales the correlation matrix by the unique parts of the data. Therefore, variables which have the largest part of their variance in common play the largest role in estimating a particular factor space (Rummel 1970). To most clearly delineate the factors identified, the axis of each sould be rotated to find the best "fit" of loadings to the factor. This is done to find the most uncluttered loadings on each factor or its "simple structure" so it may be more easily identified (Beazley and Holland 1973). One of the goals here is to reduce as many loadings as possible to zero or near zero. Two types of rotation may be used, orthogonal and oblique. Orthogonal rotation maintains independence between factors, or more precisely, the reference vectors representing the factors are maintained at 90 degrees to one another. Oblique rotation (the method used in this analysis) allows the axis of the factor to be rotated independently without reference to orthogonality or independence among factors. Oblique rotation has two advantages for this type of study. First, it generally produces factors that are less cluttered and easier to understand (Cattel 1952). Second, because the factors can be expected to be intercorrelated, the factors are more accurate representations of reality; one would not expect to find factors completely independent of one another, as they are by definition in the orthogonal rotation. This ability to correlate the factors identified sometimes sheds further light on the character and relationship of the factors (as it did in this study).

The final step in this factor analysis was the generation of factor scores on the data cases, or more precisely, composite factor score estimates. When principal-components analysis is used, these factor scores are exact; however, with other methods of factor analysis, such as the canonical one used here, the factor scores are estimates because the factors themselves are estimates. The method used in this analysis was the Complete Estimation Method outlined by Harman (1967). Factor scores in this method are derived from the factor-score coefficient matrix, F, which is derived from the formula:

$$F = S^t R^{-1},$$

where S is the rotated factor structure matrix and R is the correlation matrix. Finally, a composite scale of factor scores of each variable contributing to the factor is constructed. These columns of factor scores are multiplied by a vector of standardized scores on each data case for the variables analyzed. Thus:

$$f_1 = F_{px1} z_n,$$

where f_1 is the factor score of case one on factor one, F_{px1} is a column vector of the factor-score matrix representing factor one, and z_n is the factor of standardized scores of the data case (thus z_1 would equal the observation of the data case on variable 1 minus the mean of variable 1 divided by the standard deviation of variable 1).

The resultant factor scores on each county are shown in table 2. These factor scores were used to map the theoretical distribution of each factor (see Appendix C).

All the preceding statistical procdures were accomplished with the aid of the Statistical Package for the Social Sciences and the IBM 370 computer at Southern Illinois University, Carbondale.

Table 2. *Composite factor score estimates on county observations*

County name	F_1	F_2	F_3	F_4	F_5
Alexander	−0.305120	1.57906	0.175935	−0.503038	−.0893898
Gallatin	−.469591	−.259754	−.703234	−.957866	.769215
Hardin	−.870766	.310784	.312913	.559750	−1.534380
Jackson	1.570994	−1.338387	.061290	2.024730	1.957957
Johnson	−.948708	−.378441	.061215	−.261693	.005022
Massac	−.025608	−.503883	−1.164662	−. 227486	−.500794
Pope	−1.074966	1.110172	2.348356	−.022760	−.580330
Pulaski	−.642147	1.854515	−.896805	−.471423	−.489248
Saline	−.100847	.315961	−.369071	.112164	.771990
Union	.309991	−.814474	.650498	−.875386	.700261
Williamson	1.946526	−.822488	−.476451	1.742540	−.204787

APPENDIX C

SYMAP PROCEDURES USED FOR FACTOR MAPS

SYMAP is a computer package created by the Laboratory for Computer Graphics and Spatial Analysis at the Harvard Center for Environmental Design Studies, Harvard University. Version five was utilized in this study.

To generate the computer-based maps shown in the factor analysis results, composite factor score estimates were derived for each county observation on each factor (this procedure is explained in Appendix B). These factor scores were then used to map the intensity of the factors in each county, using the scores as data values placed at subjectively selected points in the county depending on the characteristics of the factor.

The SYMAP program utilized four sets of information. The A-outline package delineates the outline of the study region. This outline is constructed by defining vertices on a coordinate system. Their locations are based on the same coordinate system. Next, the corresponding data values for each data point are read in the E-values package. Finally the F map package defines the options that will be taken in regard to map format and data treatment.

The maps produced for this study are statistical contour maps with isolines connecting areas of equal values. The shape of these areas is controlled strictly by the placement of data points (a subjective judgment) and options chosen in data treatment. The program divides the data values into a number of equal or unequal ranges (depending on the user's need), and then interpolates the isolines between data points using a minimum of four and a maximum of 10 data points within a specified search radius. In generating these maps the standard options were taken.

In all cases except in mapping the National Forest factor, the data point chosen for each county observation was the point of highest population. In all cases except one this was the county seat. The only exception was Jackson County, where Carbondale is considerably larger than the county seat, Murphysboro. The data points for the National Forest factor were placed inside the Purchase Area Boundary in the area of heaviest Forest Service ownership. In addition, three dummy data points were added on this particular factor map to prevent large spill-overs resulting from interpolation problems at the edges of the study area.

A question may be raised as to why population centers were used in mapping factor five, agricultural intensity. One must remember that the factor, as identified in this analysis, is primarily an economic one; therefore, by placing the data point in the population center for the county, it is also placed at the probable center of wealth in the county where its net effect would be most important.

A second question which might arise concerning this procedure is the exactness of the process in defining actual boundaries and area definition. First, and most important, isopleth maps of the type produced here have a tendency to smooth and blur distinct boundaries. Therefore, they are presented only as a general, visual tool in understanding the concepts presented. Second, the interpolation does not define fixed boundaries (such as the National Forest purchase area); this results in "spilling over", especially on the borders of the study region. The interpolation process becomes more exact as the number of data points increases; however, the observational net was fairly large, thus, the distributions presented are quite general and should not be viewed as absolute in any sense.

County boundaries, purchase area boundaries, county names, and other relevant information have been added to make the maps more readable. The following two pages display a typical input of data used to generate a factor map.

```
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A-OUTLINE
 1.   5.   20.   27.   14.   9.
 1.  15.   19.   24.   11.   8.
 3.  15.   18.   22.   12.   7.
 3.  24.   18.   18.    7.   7.
 2.  24.   18.   17.    6.   6.
 2.  37.   19.   15.    5.   4.
 3.  38.   20.   15.    4.   3.
 4.  37.   21.   15.    3.   4.
 5.  39.   23.   15.    2.   5.
 6.  38.   23.   13.    1.   5.
 7.  36.   20.   12.
 8.  36.   21.   12.
 9.  37.   22.   12.
 0.  38.   21.   11.
 1.  38.   22.   12.
 2.  34.   21.   10.
 3.  33.   19.   10.
 4.  29.   18.    9.
 5.  29.   17.    8.
 6.  29.   16.    8.
 7.  30.   16.    8.
 0.  29.   15.    7.
B-DATA POINTS
 10.   10.
  9.   34.
  9.   17.
  9.   27.
 12.   21.
 12.   32.
 12.   10.
 12.   27.
 17.   10.
 18.   16.
 17.   25.
  5.   14.
 21.   11.
  5.   36.
99999
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 -0.476451
 -0.369071
  0.061215
  0.312913
  0.650498
  2.348356
  0.175935
 -0.896805
 -1.164662
 -0.500000
 -0.500000
 -0.500000
99999
F-MAP=X
C
C
C
  1    9.   12.
  2    1.    1.   24.   39.
  3    4.
 14    0.5   0.5   0.5   0.5
 26
99999
999999
/*
//
```

* U.S. Government Printing Office: 1979—667-796/76 Region No. 6

Spencer, David, and Ronald I. Beazley.

1979. The economic and geographic impact of national forest land on counties in southern Illinois. U.S. Dep. Agric. For. Serv., Res. Pap. NC-172, 27 p. U.S. Dep. Agric. For. Serv., North Cent. For. Exp. Stn., St. Paul, Minnesota.

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HOME RANGE LOCATION of white-tailed DEER

Michael E. Nelson

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1979

HOME RANGE LOCATION OF WHITE-TAILED DEER

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It is generally accepted that disturbances such as fire and logging improve deer (*Odocoileus virginianus*) habitat and increase deer numbers in heavily forested regions. Many studies have reported increased browse production and utilization, higher deer numbers, and higher hunter harvests following natural and human-caused disturbances to forest habitat (Westell 1954, Taylor 1956, Halls and Crawford 1960, Behrend and Patric 1969, Krefting and Hansen 1969). However, these increases could result from greater productivity by resident deer in response to better range, migration to the improved range, or simply from a redistribution of feeding activity by resident deer.

Most early habitat studies were conducted without the knowledge of local deer movements and most assumed real increases in deer numbers were occurring, or that deer migrated to the better range. However, recent work in northeastern Minnesota has indicated that migrations and home ranges were traditional and appeared to be determined more by early social experience and learning than by habitat (Nelson and Mech [In press.]). It is now apparent that deer movements are a complex part of deer ecology and should be examined when proposing or evaluating habitat management.

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The purpose of the present paper is to report on home range location and how it is influenced by movement traditions, social bonds, and available habitat.

STUDY AREA

The study area was located in the Superior National Forest (SNF) of northeastern Minnesota and encompassed roughly 5,300 km^2 (fig. 1). Half of the area was accessible by logging roads, and half was located in the roadless part of the Boundary Waters Canoe Area (BWCA).

The common soils of the area are clay loam, sandy loam, and peat (Grigal and Arneman 1970). The climate is cool-temperate (Hovde 1941) with snowfall averaging over 150 cm during 5 months of winter beginning in mid-November.

Plant communities of the area were described by Buell and Niering (1957) and Ohmann and Ream (1971). The upland forests are mixed coniferous-deciduous, with balsam fir (*Abies balsamea*), white spruce (*Picea glauca*), jack pine (*Pinus banksiana*), black spruce (*Picea mariana*), aspen (*Populus tremuloides*), and white birch (*Betula papyrifera*) predominating. Wet lowlands are forested by black spruce, tamarack (*Larix laricina*), white cedar (*Thuja occidentalis*), and black ash (*Fraxinus nigra*).

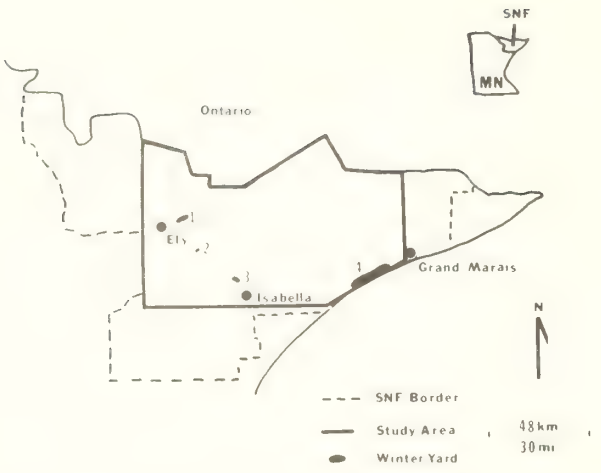

Figure 1.—*Study area.*

The northern part of the study area is inside the BWCA, of which 40 percent has never been directly altered by man and is forested with mature timber (Heinselman 1973). Areas logged in the late 1800's and early 1900's now support mature forests also. In contrast, much of the southern portion has been logged within the past three decades. Peek *et al.* (1976) provided the management history of these forests. The deer in this study lived in both regions and overwintered in the Garden Lake, Kawishiwi Campground, and Bushel Lake deeryards (Nelson and Mech [In press.]).

Deer home ranges were forested with various combinations of the following major forest types: 120-year-old jack pine, 40-year-old jack pine plantation, 100-year-old lowland black spruce, 30- and 90-year-old aspen, 12- to 20-year-old jack pine-aspen (the jack pine was planted), and 0- to 1-year-old aspen in a clearcut.

The major causes of deer mortality in the study area are human hunting and predation by wolves (*Canis lupus*) (Nelson and Mech [In press.]).

METHODS

Deer were captured on their winter ranges by means of a rocket net, traps, and drug-loaded darts. Most deer were immobilized via phencyclidine hydrochloride (Sernylan, Bio-ceutics Laboratories, Inc.)[2] combined with promazine hydrochloride (Sparine, Wyeth Laboratories, Inc.) (Seal *et al.* 1970). Some fawns were handled without drugs.

Once immobilized, all deer were sexed, ear-tagged, weighed, classified as a fawn or adult, blood-sampled, and radio-collared (Cochran and Lord 1963). Analysis of 24 parameters of hematology, blood chemistry, and endocrinology were made and interpreted (Seal *et al.* 1978). The radio collars and receiving equipment were built by the University of Minnesota Bioelectronics Laboratory and the AVM Instrument Co., Champaign, Illinois.

Deer were radio-tracked from the ground (Marshall and Kupa 1963) and from aircraft (Mech 1974). Location error for ground tracking averaged 0.4 ha (0-2.2 ha) and was minimized by obtaining radio fixes within 0.4 km of the deer and by taking bearings at approximately right angles (Heezen and Tester 1967). The location error for aerial tracking was measured at 0.02 to 1.87 ha (Hoskinson 1976).

Relocation rates varied from one to five fixes per day, with the higher rates providing the habitat selection data. Tracking was distributed during three periods of the day: 0600-1000 hours (early), 1000-1800 hours (midday), and 1800-2200 hours (late). Little tracking was done from 2200 to 0600 hours and was eventually lumped with the early-late data. Deer were tracked May through August, but most intensively in July and August. All deer were radio-tracked at least once a week throughout the year as a part of another study (Nelson and Mech [In press.]).

All tracking data were plotted on aerial photographs (scale 1:15840), and each deer's home range was determined by the minimum area method (Mohr 1947). The habitat (dominant tree species) the deer was in was recorded for each deer relocation. Habitat type boundaries and classifications were verified from USDA Forest Service records, aerial photographs, and aerial inspection. Some error polygons (Heezen and Tester 1967) from the ground tracking included more than one habitat type, so they were subsequently excluded from the data.

[2]*Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.*

The habitat selection data were analyzed separately for each deer since there were differences in types and proportions of the various habitats available to each deer. Chi-square tests of independence were used to determine differences in habitat use between months and between time-of-day tracking periods. Differences were considered significant at $P<0.05$ and highly significant at $P<0.005$. Data with significant differences were subsequently treated separately while nonsignificant data were lumped. Monthly and period-of-day data were next tested by goodness-of-fit comparisons to determine if major habitat types were used in proportion to their availability.

The hypothesis was that a deer used habitat types in proportion to their occurrence within the deer's home range. A significant result implied that the deer did not select habitats in proportion to availability. Next, 90 percent confidence intervals were determined for the proportion of observed use for each habitat type in order to determine significant differences for expected and observed utilization (Neu *et al.* 1974). Habitats that were used more than expected were considered "preferred" while those that were used less than expected were considered "avoided". Confidence intervals were not constructed for data failing to meet the sample size criteria of Neu *et al.* (1974). Determination of habitat preferences from those data was therefore more subjective.

An examination of food habits and feeding strategy was beyond the scope of this study. Discussion of feeding is, therefore, based only on cursory observations.

RESULTS

Forty-six deer were captured and radio-collared from 1974 to 1977 for studies of deer migration, home range, and social organization (Nelson and Mech [In press.]). Seven of these (one adult buck, two adult does, and four 12-month-old buck fawns) were subsampled to examine summer habitat selection. Two of the fawns (Nos. 320 and 372) were the offspring of one of the does (No. 318).

Two 12-month-old buck fawns, No. 342 in 1974 and No. 68 in 1975, provided the most detailed data on habitat usage and offered the opportunity to examine selection differences between deer inhabiting the same area. These fawns were nonmigratory and summered in the same area; each was shot by hunters the fall after it was studied. Both were radio-tracked three to five times a day; the dawn, dusk, and night hours provided three-fourths of the data, daylight the rest (table 1). Buck fawn 342 was located almost exclusively from the ground, but buck 68 was tracked from aircraft 45 percent of the time. Both deer had similar size home ranges (table 1).

The remaining five deer (one adult buck, two adult does, and two sibling buck fawns) migrated to their summer ranges and were located from aircraft almost daily in May and twice a day during three 10-day tracking periods in June, July, and August 1975 (table 1). Doe 318 and her fawns (Nos. 320 and 372) occupied the same summer range even though the fawns split apart from their mother (Nelson and Mech [In press.]). The other doe (No. 66) established a home range which overlapped with doe 318's range, but their centers of activity (Hayne 1949) were different (Nelson and Mech [In press.]). The adult buck (No. 64) summered in a different area entirely, but the habitat of his home range was similar to the habitat available to these other deer.

Table 1.— *Location and home range data*

Deer	Sex	Age	Month tracked	Locations[1] E	M	L	Total	Home range
		Years		*Number*				*Hectares*
68	M	1	June	8	11	12	31	
			July-August	36	20	45	101	177
342	M	1	July 13-Sept.18	36	34	45	115	120
318	F	Adult[2]	May-Aug.	18	30	26	74	199
320	M	1	May-Aug.	19	29	26	74	197
372	M	1	May-Aug.	14	32	29	75	220
64	M	Adult[2]	May-Aug.	13	24	22	59	549
66	F	4	May-Aug.	19	34	27	80	100

[1]Period of the day: E=early; M=middle; L=late.
[2]Age unknown.

Habitat Selection

Bucks 68 and 342 inhabited the exact same area and utilized the same forest stands. The habitat within their home range included stands of 30- and 90-year-old aspen and 100-year-old lowland black spruce, two aspen clearcuts, and a 40-year-old jack pine plantation. The two deer each had similar proportions of these types available (table 2.)

Habitat selection by buck 68 varied significantly between months; the June data differed from the July-August data ($P<0.005$). The June data did not allow a test for time-of-day differences in selection. The subsequent "goodness of fit" comparison for June showed that buck 68 used the mature aspen habitat more and the other types less than expected based upon their proportions within his home range ($P<0.01$, table 2). Lowland black spruce was not used, although it constituted 5 percent of his range.

No. 68's July-August data showed large differences in habitat selection between midday and early-late hours ($P = 0.01$). During early and late hours the buck preferred aspen clearcuts (second season of growth) and avoided mature aspen and black spruce types ($P<0.005$, table 2). The mature

Table 2.— *Habitat selection analysis for bucks 68 and 342*

Deer	and period	Habitat	Proportion of each habitat	Locations: Number expected in each habitat[1]	Locations: Number actually observed	Locations: Proportion with 90% confidence interval[2]	Selection[3]
68	June	Aspen	0.66	20	29	[4]0.94	+
	Morning through evening	Clearcut	.20	6	1	[4].03	—
		Plantation	.09	3	1	[4].03	—
		Spruce	.05	2	0	[4].00	—
		Total	1.00	31	31	1.00	
	July 1 to Aug. 31	Aspen	.66	53	43	.53 ± .12	—
	Morning and evening	Clearcut	.20	16	33	.40 ± .12	+
		Plantation	.09	7	5	.06 ± .06	0
		Spruce	.05	5	0	.00 ± .00	—
		Total	1.00	81	81	1.00	
	Mid-day	Aspen	.66	13	18	NS	
		Clearcut	.20	4	2	NS	
		Plantation	.09	2	0	NS	
		Spruce	.05	1	0	NS	
		Total	1.00	20	20	NS	
342	July 13 to Sept. 18	Aspen	.65	53	46	.57 ± .12	0
	Morning and evening	Clearcut	.13	10	29	.36 ± .11	+
		Plantation	.13	11	4	.05 ± .05	—
		Spruce	.09	7	2	[4].02	—
		Total	1.00	81	81	1.00	
	Mid-day	Aspen	.65	22	29	[4].85	+
		Clearcut	.13	4	1	[4].03	—
		Plantation	.13	5	4	[4].12	0 or —
		Spruce	.09	3	0	[4].00	—
		Total	1.00	34	34	1.00	

[1]If deer randomly located

[2]Proportion observed = $\frac{\text{number observed in each habitat}}{\text{total number observed}}$

[3]If proportion observed is higher than proportion expected selection (+); if lower, selection (—); if same, selection (0).

[4]Sample is inadequate to determine confidence interval.

jack pine plantation was used in proportion to its availability. During midday he seemed to avoid aspen clearcuts prefering mature aspen, but the comparisons were not statistically significant. The pine plantation and black spruce stands received no recorded use.

Deer 342 was tracked from July 13 through September 18 and showed no significant monthly differences in habitat usage. This is consistent with deer 68's July-August data. However, habitat selection by deer 342 did vary according to time of day. Habitat use in the early and late hours was almost identical, and it differed sharply from the midday data ($P<0.005$). As with buck 68, buck 342 used the aspen clearcuts (first season of growth) early and late in the day more than would be expected based on the proportion of clearcuts within his home range ($P<0.005$, table 2). In doing so, he avoided the mature jack pine plantation and black spruce lowlands. Mature aspen stands were used in proportion to their occurrence. Disproportionate selection of habitat was not highly significant for the midday period ($P<0.05$). He avoided the clearcuts during midday and used the mature aspen stands more than expected (table 2). He was neutral to or avoided the pine plantation at midday and avoided the black spruce type at all times (table 2).

The other five deer lived in areas with habitat types different from those available to deer 68 and 342. Available were 120-year-old jack pine, 30-and 90-year-old aspen, 12- to 20-year-old jack pine-aspen (planted jack pine), 100-year-old black spruce, and wet lowland grass. Data from these deer were more scanty (two observations per day) and included only daylight tracking periods. Four of the deer (Nos. 64, 318, 320, and 372) showed no differences in habitat selection between months or among three periods of daylight.

Nonetheless, there were highly significant differences between expected and observed use of habitat ($P<0.005$), and all four deer made similar choices (table 3). There was a marked preference for the jack pine-aspen type, a common avoidance of the black spruce type, and neutrality to or avoidance of the lowland grass type. Three of the four deer used mature aspen in proportion to its occurrence. Two of the three deer that had mature jack pine available used it in proportion to its availability, and the third avoided it.

The fifth deer, doe 66, had different habitat available and selected different habitat from other deer. Her habitat usage in May-June was different from that in July-August ($P<0.025$). She used mature aspen more than expected in early summer (table 3), and was neutral to jack pine-aspen and lowland types at that time. By late summer she was using the jack pine-aspen less than expected considering its availability, and the wet lowland grass type more than expected. The mature aspen and black spruce types were used according to availability. Time-of-day differences in the data were not statistically significant, but they did suggest a selection for wet lowland grass late in the day. The late observations showed a highly significant preference for lowland grass, ($P<0.005$), while early and midday data showed no such trend.

Three of the four deer that showed similar preferences in habitat were members of the same family group (doe 318 and fawns 320 and 372). As indicated earlier, the 12-month-old fawns were separated from their mother during summer. However, the siblings were together 80, 40, and 100 percent of the time in June, July, and August, respectively (Nelson and Mech [In press.]).

Activity

Both telemetry and direct observation provided information on the activity patterns of deer 68 and 342 as they selected habitats in July and August.

Table 3.— *Habitat selection*[1] *by deer 64, 66, 318, 320 and 372*[2]

Deer	Mature Jack pine	Young Jack pine-Aspen	Mature Aspen	Black spruce lowland	Lowland grass
318	–	+	0	–	–
320	0	+	0	–	–
372	0	+	0	–	–
64	NA[3]	+	–	–	0
66:					
(May-June)	NA[3]	0	+	0 or –	0 or –
(July-Aug.)	NA[3]	–	0	0 or –	+
(Late only)	NA[3]	0	0	0 or –	+

[1]Selection: + = "for"; – = "against"; 0 = "neutral".

[2]Deer 320 and 372 were the yearlings of deer 318 and lived within her home range during the tracking period. Deer 66's home range overlapped 318's range. Deer 64 lived in a different area.

[3]Not available.

The thick cover in the aspen stands preferred by both deer during midday did not permit much observation. However, the facts that both deer were often flushed from beds in those stands and that there was also considerable sign of feeding there, indicates the stand was used for both feeding and bedding. By late afternoon, both deer moved into the clearcuts where they were observed feeding on the large leaves of aspen suckers. The radioed deer, and other deer, fed and bedded in the cutting during the night but moved back to the timber at dawn.

Data from a different deer (doe 128) indicated that activity is least during the day and greatest after sunset. Doe 128 was radio-tagged with an activity transmitter in late July 1977 and was monitored for 41 hours on 9 days in late July and early August. She was active throughout the day, especially between 1600 and 0200 hours (fig. 2). She was not active at dawn, as bucks 68 and 342 typically were, but the data are scanty and should be examined only for a general view of activity. Other workers have observed long periods of inactivity during the day in summer with increased activity early and late in the day (Kammermeyer and Marchinton 1977). The activity is usually a result of movement into open feeding areas at sunset and a return to cover at dawn (Montgomery 1963, Thomas 1966, Marchinton and Jeter 1966, Tibbs 1967).

Migration Tradition and Habitat Availability

Four of the five migratory deer examined for habitat preferences in this study migrated 8 km between the same winter and summer ranges for the 3 years they were studied (Nelson and Mech [In press.]). The fifth deer (buck 64) made one 14-km spring migration but was killed by wolves during his return migration the next winter. The fawns of doe 318 migrated with their mother during their first fall and spring and were even found with her on their summer range 2 weeks before their second birthday.

All four deer wintered adjacent to the preferred clearcut habitat used by bucks 68 and 342, and all migrated through aspen clearcuts on the way to more mature habitat in their summer ranges. In fact, yearling bucks 320 and 372 made a few midsummer forays to those clearcuts, but such visits were of 1 or 2 days duration. At 2 years of age, buck 320 dispersed to an area adjacent to his winter range and used young aspen clearcut within that area. However, he continued to make a spring migration to his birth home range until he was killed there by wolves when 4 years old. Buck 372 continued to summer in the area of his birth and was shot when he was 2.5 years old. Another buck fawn in the only other family group studied also adopted the migration tradition and home range of his mother. He was either migrating or making a rutting movement when shot at 2.5 years of age.

Other radioed deer made similar traditional migrations through habitats preferred by some deer to habitats avoided by others. For example, three other adult does made the same migration as does 318 and 66, one of which was an associate of No. 66. One of the others migrated with her fawns to the mature pine habitat available to, but avoided by, No. 318. Two other does from a different deeryard migrated through young clearcuts and summered in very old conifer habitats. Finally, one orphaned female fawn (No. 116) wandered extensively for 2 weeks during her first spring (Nelson and Mech [(In press]). Her movements took her through several clearcuts, a 4-year-old burn, and other young forest areas, but she returned to her winter range which was dominated by mature aspen. (Her radio expired in early summer.) Similar behavior was observed in Arkansas where two radioed deer inhabited a pine forest when other deer only a few kilometers away avoided the pine type in favor of a burned area (Pledger 1975).

DISCUSSION

Intensive tracking data on two fawns using the same area during different summers indicated that the two deer used their habitats similarly. This suggests that certain habitats are preferred over others and that different deer will display the same pattern of selection when presented with the same choice of habitat. One of the two also demonstrated that habitat selection during summer can change in response to browse availability. The tracking period on the second deer was too short to detect any seasonal change.

The June data from one of the fawns indicated that the mature aspen type was preferred while a clearcut was avoided. Radioed deer elsewhere in

Figure 2.—*Activity of Doe 128, tracked in late July and early August 1977.*

northern Minnesota also avoided a clearcut in late spring and early summer (Pierce 1975). Both cases suggest that clearcuts may be of limited value during that period.

Other workers have suggested that there is a selection for grassy openings in spring and early summer (McCaffery and Creed 1969, Kohn and Mooty 1971, Pierce 1975). Roadsides and small openings were available to the one deer I intensively tracked in early summer, and I did see him feeding along a grassy road in May, however, the tracking rate was too low and the error too large to quantify such selection during that month. Other radioed deer were occasionally seen feeding in open areas, suggesting that selection for open sites was possibly occurring.

In contrast to early summer, the July and August data from the two yearlings indicated that the aspen clearcuts were highly preferred over the mature timber as feeding areas early and late in the day. The shift may have been due to extensive browsing of aspen leaves which were not available until late June and which were only available in quantity in that habitat. A change in availability of associated species may have also been partly responsible. Kohn and Mooty (1971) observed intensive use of clearcuts in northern Minnesota in July and August. Pledger (1975) documented a similar selection for a burned area and avoidance of pine forest in Arkansas. Shifts in movement as a result of changing food supply have also been reported by Byford (1970) and Pledger (1975).

Movements from the clearcuts at dawn were probably the result of a need for cover (security from predation) and possibly shade. Other radioed deer in subsequent years have bedded during the day in 4- and 6- year-old aspen clearcuts composed of dense stands of 3 m tall aspen. Apparently such stands provide adequate daytime cover.

The less intensive data from the other radioed deer also showed a habitat selection response. Four of five deer showed a preference for young jack pine-aspen while avoiding or using proportionately mature jack pine, aspen, and lowland black spruce habitats. The fifth deer (doe 66) showed a late summer and late-in-the-day selection for a grassy stream where it fed on aquatic vegetation (Hennings 1977). In contrast to the other four deer, she avoided the young jack pine-aspen type when selecting for the stream area. Her example suggests that individual differences in habitat usage do exist since her home range actually overlapped with three of the other four deer. Those other three deer were seen using aquatic sites but only in early summer and not with the same intensity as doe 66.

The radioed deer in this study generally avoided or used mature upland and lowland conifer habitats proportionate to their availability during summer. This indicated that when a choice is available deer select young deciduous or deciduous-coniferous upland habitat. This is not to say that deer do not live in mature conifer habitat. On the contrary, some radioed deer studied by Nelson and Mech [In press.] summered in mature pine forests exclusively. One 2-year-old buck even used a large black spruce bog in combination with some upland conifer sites.

The data indicate that summer habitat management in northeastern Minnesota would benefit deer most if it focused on upland deciduous or deciduous-coniferous habitats. However, managers should be aware that most deer probably live where they do because of factors other than habitat preference.

The record of two does (Nos. 318 and 326) whose fawns migrated with them to their traditional ranges and continued to do so after family breakup, lends further evidence that any selection of habitat is secondary to the influence of tradition and learning. In the one case studied in detail (No. 318), the siblings selected the same habitat as their mother even after separating from her and exploring away from the immediate area. The habitats available to them at 12 to 15 months of age were, therefore, determined by previous learning. One of these yearlings was the deer that dispersed to its winter range but continued its spring migration until its death at 4 years of age.

Selection of the best habitat may be most important and reach its greatest expression in the case of dispersing yearlings. However, the few cases of dispersal I have studied indicate that new home ranges are established in areas that the dispersers have visited during migrations. The wandering and eventual return of the orphaned female fawn in this study cannot be considered dispersal, but her example does suggest the importance of learning and tradition. Dispersers are no doubt influenced by the same phenomena.

It is quite possible that differences in habitat availability and selection are related to other social factors as well. The home ranges of does 66 and 318 overlapped each other in summer 1975, but the overlap stopped during the post-fawning period and started again later in fall, suggesting that there may be some form of avoidance by does during the post-fawning period (Nelson and Mech [In press.]). Also, by summer 1977 there were two other radioed does using the general area inhabited by does 66 and 318. Their home ranges overlapped but were distributed such that each deer had its own area of use with a different activity center (fig. 3). One other study in north-central Minnesota also found a similar pattern of home range distribution of does (Waddell 1973). The effect of such a system of range use would tend to vary the proportion of habitats available to individual deer inhabiting any one area and could account for differences in habitat selection between deer.

The migrations and strong traditions of the deer in this study, and of others reported by Nelson and Mech [In press.], suggest that home range location and therefore, habitat availability, is determined more by early social experience, learning, and tradition than by some innate ability to select the best habitat.

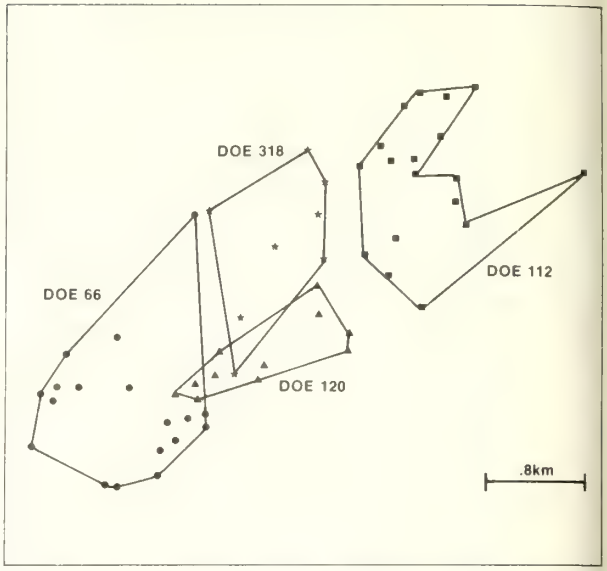

Figure 3.—*Adjacent home ranges of four radioed does in summer 1977. (The one convex boundary is the result of a lake bordering Doe 112's range.) Each doe had at least one fawn during the tracking period. Doe 66: May 9-August 24; Doe 112: May 17-September 1; Doe 120: May 9-July 2 (radio expiration); Doe 318:May 17 - June 13 (radio expiration).*

The implications for habitat management in northeastern Minnesota are: summer ranges are widely scattered so habitat management for summer range must be extensive to have any influence on the population; in winter management can be concentrated in a few major yards where most deer will be found. The goals or objectives of habitat management in this area should be designed and evaluated with respect to the migratory traditions and social behavior in the deer population. Failure to consider this aspect of deer ecology may lead wildlife managers to erroneous conclusions about the effectiveness of habitat management.

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The cost of debarked whole-tree CHIPS stump to digestor

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THE COST OF DEBARKED WHOLE-TREE CHIPS: STUMP TO DIGESTOR

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BACKGROUND

The need to increase the productivity of our forest land has been well documented by numerous investigators (Cliff 1973, USDA Forest Service 1973). With the price of timber products relative to other materials at 1970 levels, a medium projection of United States demand for roundwood indicates an increase from the 1970 level of 11.6 billion cubic feet to more than 22 billion cubic feet by the year 2000. At the same time, the commercial timber land available for growing timber products is projected to decrease by as much as 15 million acres. This situation presents a major challenge to woodland managers as well as researchers. They must consider all possible ways of producing more material from fewer acres.

One untapped source of potentially usable resources are "forest residues"—logging waste, cull trees, wind falls, thinnings, or stands considered unprofitable to harvest by current standards. If these materials were utilized, they could contribute substantially to meeting future needs. However, these residues are not usually in the form that current harvesting and processing equipment can efficiently handle—it is either crooked, small, large, or dirty. Despite the problems involved, it is inevitable that much of this residue must be utilized to meet future demand.

Logging residue is the largest single source of potential timber supplies. At least 100 million oven dry tons of wood are discarded annually in harvesting operations in the form of limbs, tree tops, and defective or broken logs (USDA Forest Service 1976) (table 1). These harvesting residues have commonly been burned in the woods or left to decay and return to the soil. Burning the debris has provoked questions about air pollution. Leaving it untreated creates fire hazards and is an aesthetic liability.

Table 1.—*Sources of forest residues by regions in the United States (USDA, Forest Service 1976)*
(In millions of tons oven dry)

Region	Yearly harvesting residues	Yearly other removals	Inventory of noncommercial timber
Pacific Coast	26	1.6	148
Rocky Mountain	6	0.2	180
South	52	11.8	375
North	26	6.0	281
Total	110	19.6	984

Vast quantities of wood are removed from the timber inventory by such operations as timber stand improvement and land clearing that are not utilized for timber products. These removals also represent a large potential supply of fiber if the technology to utilize them can be developed. Annually, 20 million oven dry tons of wood are estimated to be lost through these removals.

Another source of usable fiber are the rough, rotten, and salvageable dead trees, or "noncommercial" timber currently in our forests. Estimates of this resource are close to 1 billion tons of oven dry material or 66 billion cubic feet. The magnitude of this resource is realized when it is compared to the 13 to 15 billion cubic feet of timber being consumed annually.

The introduction of portable chippers, which operate in the woods to reduce whole-trees or tops and limbs remaining after logging to chips, has opened the door to increased use of residue materials by the paper and board industries. Reduction of the residue material to chips facilitates the handling and processing of the initially bulky and irregular material by putting it in a form that standard materials handling equipment can accommodate and the pulpwood industry requires.

The basic whole-tree harvesting system consists of: (1) feller-bunchers that sever the trees and accumulate them into bunches for subsequent forwarding to the chipper site, (2) grapple skidders to move the bunches to the chipper, (3) portable chippers that operate at a woods landing to reduce the whole trees to chips, and (4) chip vans that transport the chips to the mill (fig. 1).

Because the tops, limbs, and boles have been chipped with the bark on, the increased levels of bark and associated dirt and grit reduce product quality and increase wear on processing equipment. Most pulp mills have found that they are only able to blend a small amount of whole-tree chips with their normal pulp furnish and still maintain quality control. However, if use of whole-trees are to increase, the quality of the chip material must be upgraded.

A technically sound chip debarking system has been developed at the laboratory level (Erickson and Hillstrom 1974). A vacuum-airlift system has also been developed that, when used in conjunction with the compression debarking system, can reduce the capital cost of the debarking plant and thus lower the processing cost per ton of chips (Sturos 1978).

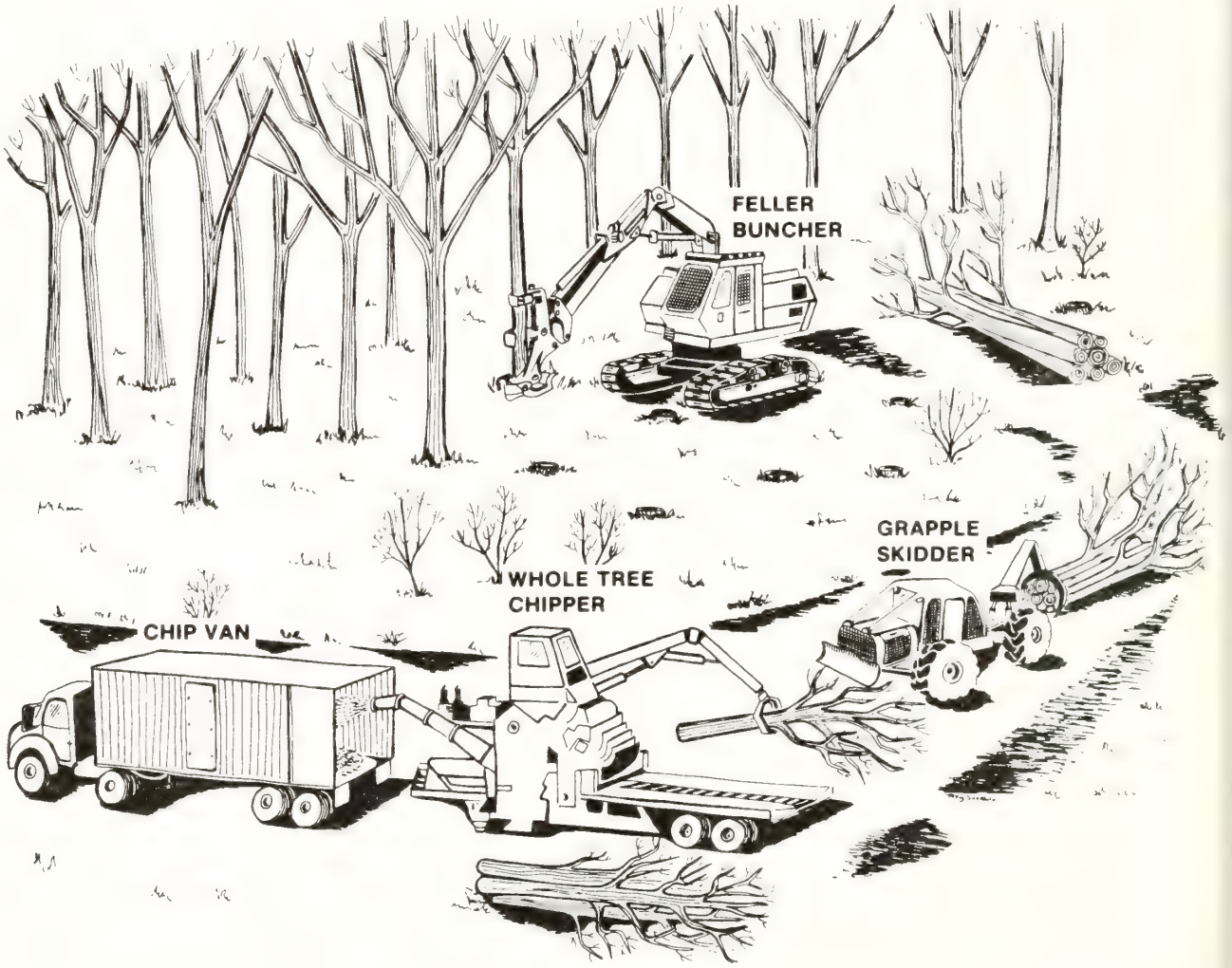

Figure 1.—*Typical whole-tree chipping equipment.*

This paper presents a cost estimate of the physical plant and machinery of a commercial-sized compression debarking plant capable of processing 60 green tons per hour. It also offers an estimate of the cost per unit of harvesting and processing unbarked chips to an acceptable level of bark content.

THE BARK-CHIP SEPARATION-SEGREGATION (BCSS) SYSTEM

The elements of this chip debarking system are presteaming, compression debarking, mechanical attrition (optional), and screening. The principal element is the compression debarker (Blanchard 1962) which consists of two oppositely rotating steel cylinders with a nip spacing smaller than the thickness of bark and wood chips (fig. 2).

A continuous single-layered flow of unbarked chips are compressed through the nip. The compression will break the bark-wood bond, cause the bark to adhere to the rolls, or fragment the bark into finer particles. Bark adhering to the rolls can be scraped from the rolls into the waste area. The fragmented material can be screened out (the optional mechanical attrition treatment increases the amount of fragmented bark). The effectiveness of the compression is dependent upon the condition of the raw material. If it is green and chipped during the growing season, the bark will readily adhere to the rolls. Up to 50 percent of the input

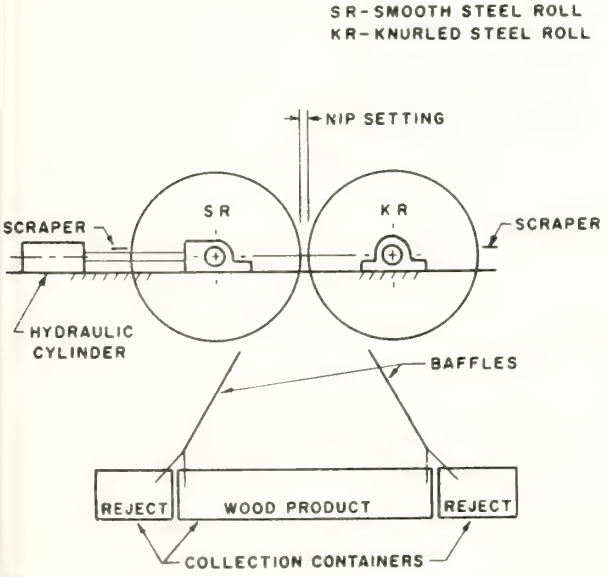

Figure 2.—*Simplified schematic diagram of the compression debarker.*

bark in whole-tree chips can be removed by compression debarking alone (Mattson 1975). If the chips are steamed prior to compression, bark removal is greatly improved and most of the seasonal effect is eliminated. This steaming treatment can increase compression debarking efficiency up to 85 percent bark removal (Erickson 1976, Mattson 1975).

Most of the residual bark in the "clean" chip mass after steaming and compression is concentrated in the smaller size classes. If a minimal level of bark is desired in the compression debarker output, the minus ⅜-inch size class can be screened out. This screening will reduce the bark content of whole-tree chips of the major Lake States pulpwood species to an average level of 5 percent or less with total bark removal more than 80 percent (table 2). To illustrate, 100 pounds of as-received aspen input material contained 20.6

Table 2.—*Compression debarking results for whole-tree chips*[1]

(In percent)

Month	Input bark	Output bark	Input bark removed	Input foliage	Output foliage	Input foliage removed	Input wood recovered	Total material removed
ASPEN								
Jan.	22	3	89				91	27
Mar.	19	2	90				92	24
May	21	2	94				93	25
July	20	2	92	1	1	43	92	25
Sept.	21	2	92	1	1	34	92	26
Nov.	20	3	89				93	24
Average	21	2	91	1	1	39	92	25
SUGAR MAPLE								
Jan.	14	2	91				84	26
Mar.	13	2	87				90	20
May	14	4	79				88	22
July	14	4	82	2	2	40	80	29
Sept.	14	3	82	2	1	54	82	28
Nov.	14	3	83				89	21
Average	14	3	84	2	1	47	86	24
JACK PINE								
Jan.	10	1	89	3		91	79	30
Mar.	9	2	87	3	1	88	85	24
May	12	2	88	5		95	88	26
July	10	2	85	4		96	87	24
Sept.	11	2	87	4		95	81	26
Nov.	10	3	80	5		94	85	25
Average	10	2	86	4		93	84	26

[1]Presteamed for 5 min. at 30 PSI, compression debarked, minus ⅜-inch size fraction screened off. All results on oven dry basis.

pounds of bark, 1 pound of foliage on an oven dry basis, and 78.4 pounds of clean wood. After steaming, compression, and screening off all material under ⅜-inch, 25.2 pounds of material has been removed, leaving 74.8 of the original 100 pounds. Of this 74.8 pounds, 1.8 pounds is bark, 0.6 pound is foliage, and 72.4 pounds is wood. The amount of removal has been 91 percent of the original bark and 39 percent of the original foliage.

HARVEST AND TRANSPORT COSTS OF WHOLE-TREE CHIPS

The harvest and transport costs of whole-tree chipping operations vary with equipment, stand, terrain, and distance to the mill. For this paper we will assume a typical harvesting situation and project a reasonable cost of supplying whole-tree chips to a mill.

To estimate the cost of whole-tree chips, we will assume: clearcut material is of average quality from aspen stands, distance from stump to mill is 50 miles, the operator has enough equipment to provide a constant flow of chips, and stumpage charge is based on total removal of chips.

Typical equipment an operator might have are: accumulating head feller-buncher(s), grapple skidder(s), whole-tree chipper, chain saws, fuel truck, maintenance truck, chip vans, highway tractors, and landing tractor.

The crew size required to support this equipment ranges from 5 to 10 and the purchase cost of the equipment exceeds $300,000.

The following tablulation presents estimated costs of supplying aspen whole-tree chips to the mill under the above assumptions.

Green Aspen Whole-tree Chips Delivered to Mill:

	$/Green Ton
Chips to van	6.25
Harvest equipment &labor—$5.00	
Misc. (Insurance, Roads, etc.)—$1.25	
Transport to mill (Approx. 50 mi.)	3.00
Stumpage	2.00
TOTAL TO MILL	11.25
Mill yard handling	1.00
TOTAL TO BCSS PLANT	12.25

BCSS PLANT COST ANALYSIS

The cost to process unbarked whole-tree chips through the BCSS plant was developed from the basic engineering data concerning the process flow obtained by laboratory testing, manufacturers cost estimates of equipment, and standard estimating factors for other physical plant costs based on the installed cost of process equipment (Cooledge and Pfeiffer 1956). The estimate is at a preblueprint stage and is only intended to give an initial indication of economic factors affecting the feasibility of compression debarking of whole-tree chips. Real proposed installations are unique cases and must be considered individually.

The following basic assumptions were made to arrive at the estimate:

- The scale of operation is mid-range, neither unusually large or small.
- The plant is independent of other operations for facilities and materials.
- All plant facilities are owned and not leased.
- All construction costs are included and there are no zero cost contributions of labor or other items.
- All materials and equipment are purchased new at normal prices with no extraordinary features.
- Construction costs will not be affected by excessive delays in plans or unusual time restraints.

Based on the laboratory results for a process of presteaming, compression debarking, and screening, the material balance for a production scale plant of 60 tons per hour (green weight basis) is tabulated for three typical Lake States species (table 3). The material balance dictates the size of process equipment required to handle the maximum amount of material expected at each stage of the process.

Using the material balance (table 3), equipment requirements of the plant flow diagram (fig. 3), and manufacturers estimates of costs for the hardware, the capital and operating costs of the 60 ton per hour plant were calculated as follows:

Table 3.—*Production for 60 ton per hour compression debarking plant*

Item	Aspen	Sugar maple	Jack pine
Input (green tons)	60.0	60.0	60.0
Input (dry tons)	31.8	38.0	29.2
Input moisture content[1] (percent)	47.0	37.0	51.0
Output (green tons)	43.9	44.5	39.6
Output (dry tons)	23.8	28.9	21.8
Output moisture content[1] (percent)	46.0	35.0	45.0
Rejects (green tons)	16.1	15.5	20.4
Rejects (dry tons)	8.0	9.2	7.5
Rejects moisture content[1] (percent)	50.0	41.0	63.0
Rejects bark (percent)	62.0	51.0	36.0
Rejects foliage (percent)	[2]2.0	[2]3.0	15.0

[1]Green basis.

[2]Foliage season only.

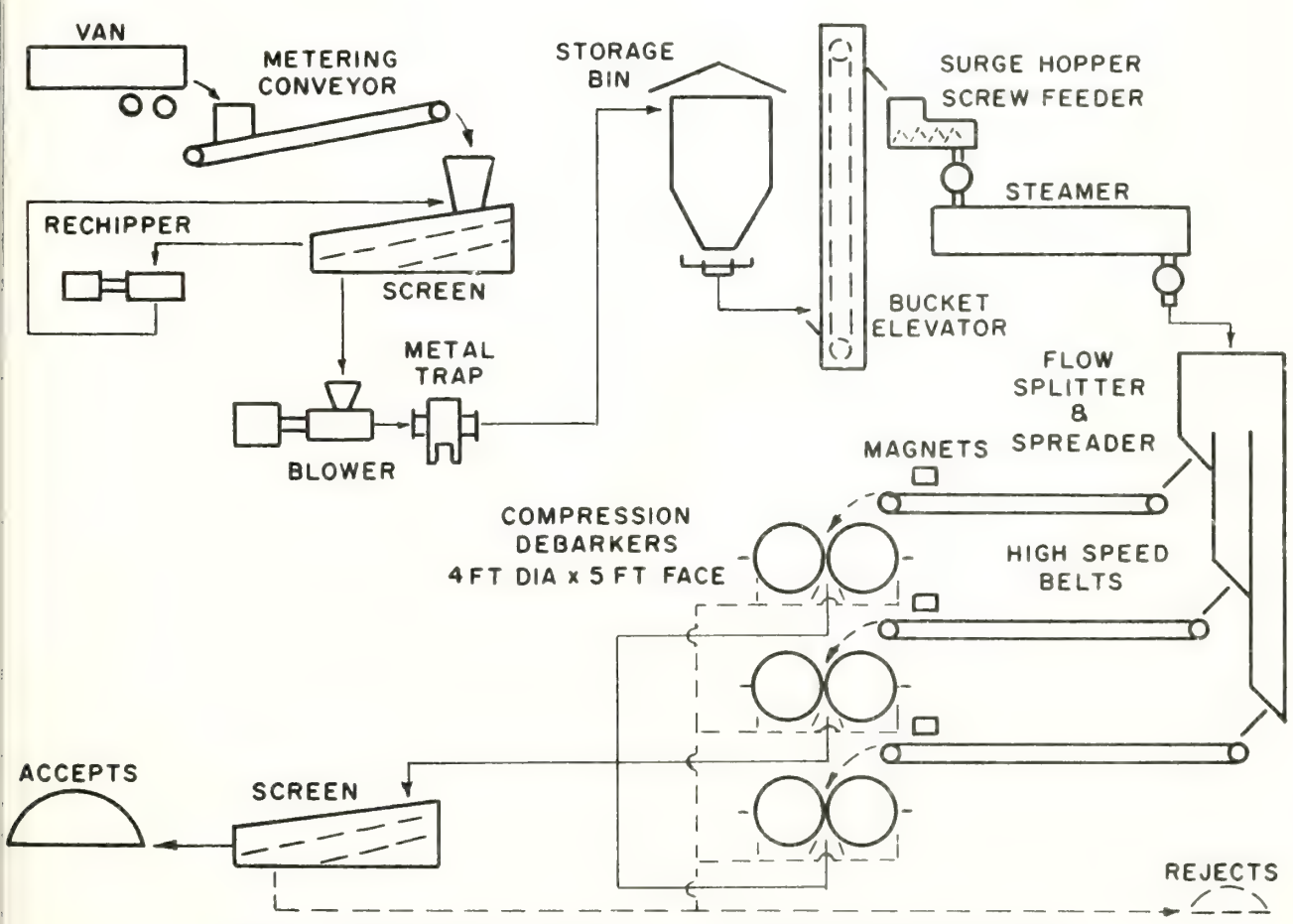

Figure 3.—*Schematic of 60 ton per hour compression debarking plant.*

COST ESTIMATE FOR 60 TON/HOUR BCSS PLANT

Equipment Cost Estimate

	Dollars
Presteamer	350,000
Compression debarker(s)[1]	857,000
Conveying Equipment	202,000
Supply hopper	56,000
Screens	92,000
Rechipper	29,000
Total delivered cost of equipment (to Green Bay, WI)	1,586,000
Installation (30%)	476,000
Total installed cost of equipment	2,062,000

Physical Plant Cost Estimate[2]

Item	Estimating factor (percent of installed cost)	Dollars
Installed equipment		2,062,000
Site preparation	5	113,000
Building & building services	20	412,000
Process piping	7	134,000
Electrical installations	9	186,000
Utilities and other services	9	186,000
Construction overhead	30	619,000
Contingencies	20	412,000
Total physical plant cost		4,124,000

Operating Cost Estimate

Estimated Annual Production: (8,000 hours/year) — 199,000 Oven dry debarked tons

	Annual cost	Cost/ output ton
Raw Material		
60 tons/hours × 8,000 hours/year × $12.25/ton =	$5,880,000	$29.55
Utilities		
Electricity:		
789 hp × 0.7457 kw/hp × 8,000 hours/year × $.024/kwh =	112,965	.57
Steam:		
60 tons/hour × 2,000 lbs./ tons × 189Btu/lb. × MBtu/ 106 Btu × $2.50/MBtu × 8,000 hour/year =	453,600	2.28
Other Utilities:	79,600	.40
Total utilities	$ 646,165	$ 3.25
Labor		
Direct:		
3 men/shift × 8,760 hours/year × $6.00/hour =	$ 157,680	$ .79
Direct Supervision Direct Labor × .10 =	15,768	.08
Payroll Overhead Direct Labor × .20 =	31,536	.16
Total labor	$ 204,984	$ 1.03

Investment Determined Cost

	Annual cost	Cost/ output ton
General Overhead Direct Labor × .55 = 157,680 × .55	$ 86,724	$ .44
Physical Plant Cost × .02 = 4,124,000 × .02	82,480	.41
Maintenance		
Physical Plant Cost × .04 = 4,124,000 × .04	164,960	.83
Operating Supplies		
Physical Plant Cost × .005 = 4,124,000 × .005	20,620	.10
Depreciation		
Process Equip. × .10 = 1,586,000 × .10	158,600	.80
Building × .05 = 412,000 × .05	20,600	.10
Taxes		
Physical Plant Cost × .02 = 4,124,000 × .02	82,480	.41
Insurance		
Physical Plant Cost × .01 = 4,124,000 × .01	41,240	.21
Total investment determined cost	657,704	3.31
TOTAL PRODUCTION COSTS	7,388,853	37.13
FUEL CREDIT (see below)	(2,432,500)	(12.22)
NET PRODUCTION COSTS	$4,956,353	$24.91

[1]*Based on 4 green tons per hour per foot of roll width, 3 units with 5-foot rolls are required.*

[2]*See Appendix for description of categories for physical plant costs.*

As a credit to the production cost of the BCSS plant, approximately 139,000 tons of reject material (50 percent of which is bark) at a moisture content of 50 percent is generated per year. This material is uniform in size and ideally suited for burning to generate process steam or power. With a fuel cost of $.35 per gallon for oil, the equivalent fuel value of this reject material would be $17.50 per ton (Arola 1975). This fuel value would give a credit of $2,432,500 per year or $12.22 per dry output ton to the production costs of the BCSS plant. Subtracting the fuel credit gives a net production cost of $4,956,353 per year or $24.91 per dry output ton. It is interesting to note that the fuel value of the reject material exceeds the production cost of the debarking plant, exclusive of raw material costs.

DISCUSSION

Any evaluation of the potential of whole-tree chips as a fiber source must consider the wood supply system in its entirety, i.e., from stump to digestor. Numerous factors not considered in this paper affect the overall economics of the system. Among the significant characteristics of whole-tree harvesting and utilization systems not considered here are the following:

- The increased yield of whole-tree chipping systems will reduce the size of the required woodshed of a mill and also reduce the average hauling distances for transport to the mill.
- The removal of all the material from the stand has positive benefits from the site preparation and regeneration aspects and also produces a site that is more aesthetically acceptable.
- The compression of the chips during the beneficiation process opens the chips along the fiber lines, which allows more rapid penetration of the cooking liquors and reduced cooking time.
- The opening of the chips reduces knot rejects and produces greater uniformity in the pulp.

The cost figures presented in this paper are only rough estimates of what might be found under actual conditions. Each pulp mill operator considering the installation of a compression debarking plant to beneficiate whole-tree chips will, of course, have to make his own analysis taking into account his individual circumstances. However, we feel the cost figures presented here indicate that whole-tree chipping and beneficiation of the chips by compression debarking is competitive with conventional fiber sources and is a feasible means of expanding wood supplies.

The costs presented are for one alternative chip quality improvement system. Another promising alternative approach is to combine the above system with air flotation.

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APPENDIX

Description of categories in physical plant costs

Site Preparation.—clearing; cleanup; grading and drainage; roads and walks; railroad and siding facilities; fencing.

Building and Building Services.—process building; warehouses; partitioning, doors and windows for offices and laboratory; lighting; plumbing for washrooms; drinking fountains; drains; ventilation; sprinkling system.

Process Piping (for materials handling).—installed costs of pipes to convey raw materials, intermediate products, finished products; steam; water; air; waste within process building.

Electrical Installations for Power Distribution.—transformers; yard distribution; wiring; power and instrument wiring within building; control centers; instrument panels; switchboards (does not include other outside costs, motor and motor starters, or building lighting).

Utilities and Other Service Facilities.—water; steam costs for generating plant (including pipes, valves, and meters); electrical costs from substation; fuel distribution air compressors and pipes; refuse disposal; fire protection; furniture; equipment.

Construction Overhead.—engineering, construction drawings; work planning and supervision; contractor's fee; home and field office expenses; insurance during construction; payroll overhead for permanent employees; property taxes; licenses and permits; interest charges on land and building during construction; depreciation of building and land during construction.

Contingencies.—Unforeseen outlays; uninsured losses; price increases.

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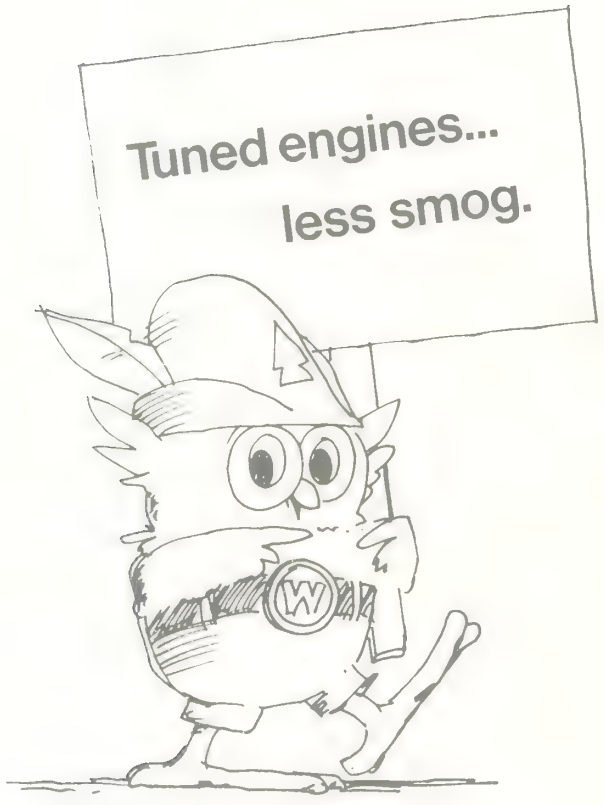
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The market for forest & associated land in southern Illinois: **implications for land management**

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THE MARKET FOR FOREST AND ASSOCIATED LAND IN SOUTHERN ILLINOIS: IMPLICATIONS FOR LAND MANAGEMENT

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Nonurban, nonagricultural land covers about one-fourth of the State of Illinois and includes forest land, brush land, unimproved pasture, and wasteland. Because most of this land is forested or in the process of returning to forest, we will refer to it as forest and associated land (F&A land) (Beazley 1965, Burde and Baumgartner 1978).

F&A land provides a wide range of goods and services—scenic beauty, outdoor recreation, forage and shade for livestock, wildlife and wildlife habitat, carbon dioxide-oxygen exchange, soil stabilization and improvement, water and watershed regulation, wood and wood products, moderation of solar radiation and wind, and filtering of various sights, sounds, and substances. These goods and services will probably become increasingly important to Illinois residents in the future.

F&A land is found in all regions of the State but mainly occurs in the southern and western portions. It generally lies along rivers and in hilly areas and in tracts that range from several thousand acres to narrow strips along fences, streams, and roadways. Much of the F&A land is intermixed with agricultural cropland.

Most of Illinois' F&A land is privately owned, but many of the benefits that it provides accrue partially to the public. For example, a particular tract may enhance the landscape; influence the quantity, quality, and timing of streamflow; and provide habitat for wildlife.

Because of the significant public benefits from F&A land, a number of public technical and financial assistance programs have been begun to enhance the management and use of the private holdings (Andresen 1972). These programs must be continually updated in terms of demands for the goods and services that the land can produce and the current and expected patterns of resource ownership, owner goals, and ongoing management efforts.

The land market is an important focus for change. It may signal major alterations in owner goals and land use that may have significant implications for resource management and land use. Frequent turnover of private land does not usually contribute to long-term investment in resource development by landowners. Breaking up large tracts into smaller ones may constrain resource management programs. The shift of a substantial amount of F&A land from farm to nonfarm may mark a land use trend toward vacation homes, recreation developments, and rural nonfarm residences.

Those responsible for technical and financial assistance programs are interested in the amount of activity in the land market, as well as the size and characteristics of the tracts exchanged and the goals and management programs of landowners. Various other groups are also interested, particularly if there are indications that F&A land will be

converted to housing or recreation developments. These groups include local government units and others who provide services to rural residents, State and local planning agencies, public resource managers, tax assessors, potential land purchasers and sellers, and wood-using industries.

The increasing public value of F&A land and a large amount of uncertainty concerning its management and use has led to a cooperative research project between the University of Illinois and the USDA Forest Service. The purpose of the project is to analyze trends in the marketing, ownership, management, and use of F&A land and to develop recommendations for enhancing this land's contributions to the people of Illinois. This report presents findings of the study of trends in the market of F&A land.

THE STUDY

We analyzed the market and the implications for resource management of F&A land in two sample counties in southern Illinois. Counties were chosen as sample units because most records on land transactions are kept at that level.

Both of the sample counties—Jackson and Union—have a substantial portion of F&A land, some of which is included in the Shawnee National Forest, and therefore provide reasonable representations of the market for such land in southern Illinois. They differ in that for some time Jackson County has experienced more rapid residential and recreational developments which are just beginning to expand in Union County.

Information was collected from a sample of 869 land transactions in Jackson County and 509 transactions in Union County for the 1968-1974 period. The sample was drawn from all land transactions of 1 acre or more (excluding contract sales, sales involving platted and subdivided town and city lots, and transactions in which money did not change hands—inheritance, trades, and gifts).[1] All purchases by the USDA Forest Service, the city of Carbondale, and a 50 percent sample of the < 1 acre transactions were included. Sample results were subsequently weighted to correct for the different sampling intensities.

Assessor records were used to obtain information on the location and size of the tract sold, amount of the tract classified as improved (crop or tillable) or unimproved (noncrop or nontillable), assessed value of the tract, the sale price and date of sale, and the address of the purchaser. Deed records were used to determine the residence of purchasers. Aerial photographs and plat maps were used to determine the extent of F&A land; the presence or absence of buildings, ponds, and streams; the type of road serving the tract; and the distance of the tract from the city of Carbondale.

IMPLICATIONS FOR MANAGEMENT

Activity in the market for F&A land has significant implications for resource management and use as well as public policy aimed at influencing management and use. Important considerations include the types of land sold in combination with F&A land, sale sizes, the extent of a tree canopy, water resources, buildings and roads on the tracts, proximity of National Forest land, the turnover of land ownership, residences of the new owners, and the price for which the land was sold.

TYPES OF LAND SOLD

The management and use of a particular tract of F&A land will be influenced by the other land and related resources held by the owner. It is likely that the owner will use all of his resources in a combination that he expects to best meet his goals. Under these circumstances, the management and use of F&A land would depend, in part, on the management and use of other resources held by the owner. For example, a 5-acre woodland on a hill in the center of a 650-acre farm, nearly all of which is in row crops, is likely to be managed and used differently than a 5-acre rural homesite that was the only land held by its owner.

[1] *It was noted during the study that a number of land transfers took place as the result of contract sales and inheritances. However, these transactions were not included in the study because sale prices were not available.*

A large portion, 70 percent, of the tracts sold in Jackson and Union Counties included some F&A land, often in combination with other types of land, particularly cropland. Less than 10 percent of the sales were entirely F&A land (table 1).

Table 1.—*Tracts sold in each category, 1968-1974*
(In percent of sales)

Land category	Jackson County	Union County	Total
F&A land combined with cropland	52	67	58
F&A land combined with another type of land excluding cropland	7	2	5
Entirely F&A land	11	5	9
No F&A land	30	26	28

SALE SIZES

The acreage of F&A land contained in an individual sale averaged only 20 acres in Jackson County and 25 acres in Union County but ranged up to several hundred acres. Of the sales that included F&A land, half had less than 10 acres of F&A land (table 2). The portion of the land sold that was F&A land averaged 31 percent in Union County and 38 percent in Jackson County. Thus, it can be expected that management of the F&A land resource that was sold will involve a number of small tracts where small acreages of F&A land are found in combination with other land resources, particularly agricultural cropland. This may complicate public assistance programs.

Table 2.—*Extent of F&A in tracts sold in Jackson and Union Counties, Illinois, that included some F&A land, 1968-1974*
(In percent of sales)

Acres of F&A	Jackson County	Union County	Total
1-9	51	45	49
10-19	14	19	16
20-29	9	8	9
30-39	6	7	6
40-49	3	4	3
50-59	2	3	2
60-69	2	3	2
70-79	2	3	3
80-89	2	1	2
90-99	3	1	2
100+	6	6	6

TREE CANOPY

Most of the F&A land sold in Jackson (85 percent) and Union (83 percent) Counties was covered by a tree canopy. The F&A land that does not support a canopy is for the most part retired pasture and cropland that is in the process of returning to forest. The rather small amount of F&A land not covered by a canopy suggests that little cropland and pasture has been retired recently from active agriculture on the tracts that were sold. This is attributable in part to high crop prices in recent years and economies of scale in farming that tend to keep cropped areas large.

The presence of a tree canopy over much of the area has implications for management and use. The trees offer a potential for conversion to wood products, influence wildlife habitat and the environment for recreation, and affect the quantity and quality of streamflow. The flows of these goods and services are heavily influenced by resource management programs undertaken by the owner. Due to the large extent of tree canopy, it is not likely that tree planting will be a major activity.

WATER RESOURCES

More than one-fourth of the tracts sold included streams or ponds (table 3). F&A land is often located adjacent to streams because those areas are not suitable for agriculture. Some ponds are surrounded by F&A land, but others are in more "open" areas. The presence of these resources may have a significant impact on the management and use of F&A land. The forest-water interface is a key habitat for wildlife and often a desirable environment for recreation.

Table 3.—*Land sales in Jackson and Union Counties, Illinois, that included a pond or stream, 1968-1974*

(In percent)

Number of ponds	Jackson County		Union County	
	stream	no stream	stream	no stream
none	14	72	10	65
1	4	8	3	15
2	([1])	1	2	4
3	0	([1])	1	0
4	0	([1])	([1])	([1])
5 or more	0	([1])	([1])	([1])

[1] Less than 0.5 percent.

BUILDINGS

Buildings were located on 48 percent of the tracts sold in Jackson County and 49 percent of the tracts sold in Union County. The presence of buildings may influence the management and use of the land, particularly if the buildings can be used as permanent or seasonal residences.

ROADS

Accessibility by automobile may have a significant influence on the use of a tract, particularly for recreational or residential purposes. Nearly three-fourths of the tracts sold in Jackson County and nearly four-fifths of the tracts sold in Union County were accessible by road. The type of roads that serve the land areas sold are shown below:

Type of Road	Jackson County	Union County
	(Percent of sales)	
None	26	19
Unimproved	4	1
Gravel or stone	38	38
Bituminous	12	21
Paved	16	16
Divided	([2])	1
Municipal	4	4

[2] Less than 0.5 percent.

PROXIMITY TO A NATIONAL FOREST

Shawnee National Forest land accounts for 11 percent of Jackson County and 13 percent of Union County. Approximately 10 percent of the land sold in Jackson and Union Counties had at least one common border with the Shawnee. Even though these tracts are usually in remote and heavily forested areas, many recreationists may be attracted to them by the nearby National Forest. Also, the Forest Service may someday wish to acquisition adjoining tracts. Therfore, proximity to National Forest land may influence how this F&A land is managed and used.

TURNOVER OF LAND OWNERSHIP

During the period 1968-1974, average annual land sales of 1 acre or more—excluding sales involving platted and subdivided town and city lots, transactions in which money did not change hands (inheritance, trades, and gifts), and contract sales—accounted for an average of 3 percent of the land in Jackson and Union Counties. This is a conservative estimate of the total amount of turnover because inheritance was excluded but is likely to be an important source of ownership turnover due to the high ages of many owners (Beazley and Holland 1973, Neuzil 1970, U.S. Bureau of Census 1977).

During the period 1968-1974, an average of 258 tracts that contained some 7,460 acres of F&A land were sold in Jackson and Union Counties each year.

No trend is evident in the acreage of F&A land sold in Jackson and Union Counties annually for the period 1968-1974. The average acreage of F&A land per sale has not shown a clear trend nor has the percent of the average sale consisting of F&A land. The portion of the tracts sold that contained F&A land has likewise shown no significant trends (tables 4 and 5).

When forest and associated land is sold, a significant change in resource use and management may occur. Studies of owners of similar resources in Illinois and elsewhere have indicated a wide range of goals, objectives, and uses. Many of the

Table 4.—*Land market activity, Jackson County, Illinois, 1968-1974*

Year	Sales			Acres sold		Average size of sale		Land tracts that include some F&A land
	All	Those including F&A land		All	F&A land	All	F&A land	
	Number		Percent			Acres		Percent
1968	153	106	46	10,808	5,027	71	33	69
1969	165	99	42	7,732	3,289	47	20	60
1970	166	95	41	6,620	2,696	40	16	57
1971	234	153	33	10,714	3,542	46	15	65
1972	298	215	49	11,712	5,758	39	19	72
1973	329	227	44	11,761	5,171	36	16	69
1974	267	177	30	11,463	3,504	43	13	66

Table 5.—*Land market activity, Union County, Illinois, 1968-1974*

Year	Sales			Acres sold		Average size of sale		Land tracts that include some F&A land
	All	Those including F&A land		All	F&A land	All	F&A land	
	Number		Percent			Acres		Percent
1968	115	93	46	9,070	4,149	79	36	81
1969	138	90	36	7,314	2,657	53	19	65
1970	115	84	35	6,274	2,214	54	19	73
1971	125	85	40	7,808	3,090	62	25	68
1972	161	127	35	11,213	3,939	70	24	79
1973	202	146	31	10,122	3,155	50	16	72
1974	149	118	44	9,321	4,133	63	28	79

goods and services provided by this land accrue to the public at large rather than to the individual owner. Thus, the financial returns to the owner are in many cases low, and are not likely to play as strong a role in resource management as is usually the case with cropland. This makes it difficult to predict the management and use of F&A land.

On the average, the transactions sampled were representative of the land in Jackson and Union Counties in that they had a similar portion of unimproved and improved land. However, it is clear that the sale of highly-productive farms in the lowland along the Mississippi River was less active and land sales near large urban centers were more active than other holdings.

It should be noted that the tracts studied are a sample of tracts that sold, not of all tracts. The tracts that sold are of particular interest because they are the potential focus for change in the management and use of F&A land and present new opportunities for public assistance programs.

With the long-term nature of forest growth, the turnover of owners of F&A land has additional implications for resource management and use. Owners that expect to sell their land after a short time may be unwilling to invest in forest management such as tree planting that bring returns in the future.

We did not look at the breakdown of specific tracts of land. However, the time series in land market activity was examined and no trend toward increased number of sales or smaller sales

was found. Thus, it appears unlikely that there is any accelerated fragmentation in the ownership of the F&A land resource.

LOCATION OF PURCHASERS

Purchasers from the local area predominated in the land market. Residents of the same or adjacent counties where the land was purchased accounted for 70 percent of the acres purchased in Union County and 67 percent of the acres purchased in Jackson County (table 6). The concentration of owners in the local area should facilitate public service programs aimed at landowners. More distant or "absentee" owners may present a more difficult problem in programs where personal contact is important.

The percentage of F&A land purchased by residence of owner did not differ substantially from the distribution of total acres sold (table 6). The one significant exception in both counties is that the USDA Forest Service purchased tracts with a high portion of F&A land.

Table 6.—*Residences of land purchasers in Jackson and Union Counties, 1968-1974*
(In percent)

Purchaser	Purchases No.	Purchases Acres	F&A land
UNION COUNTY			
Union County	73	55	47
Adjacent counties	11	15	15
Madison and St. Clair Counties[1]	2	1	1
Other Illinois	8	14	19
Out of State	5	11	11
USDA Forest Service	1	4	7
JACKSON COUNTY			
Jackson County	77	54	53
Adjacent counties	8	13	13
Madison and St. Clair Counties[1]	2	2	2
Other Illinois	3	2	3
Out of State	5	17	10
USDA Forest Service	4	11	18
City of Carbondale	1	1	1

[1] Part of the St. Louis standard Metropolitan statistical Area, the nearest such area to the study counties.

PRICES

Prices are a guide to the value that purchasers place on F&A land and offer some indication of expected use of the resource. Because F&A land is usually sold in combination with other types of land, it is difficult to identify what is being paid for a particular type of land. However, the following subsample of sales was identified that consisted entirely of F&A land or entirely of cropland that had no buildings .

	Jackson County	Union County
FOREST AND ASSOCIATED LAND		
Number of Sales	23	5
Mean Price	$351	$216
Standard Error	$132	$ 74
0.95 Confidence Interval	$78-624	$11-422
CROPLAND (IMPROVED)		
Number of Sales	112	51
Mean Price	$1,630	$867
Standard Error	$163	$145
0.95 Confidence Interval	$1,307-1,725	$575-1,158

The difference between the mean prices per acre for the two counties is not significant at the 0.95 level.

Prices of cropland varied greatly but generally tended to be higher per acre than F&A land.

The mean price for F&A land is higher than what is usually thought of as being justified by the long-term returns from timber production (Callahan 1966), although because much of the land is covered by a tree canopy, immediate returns from a timber sale may offset part or all of the sale price (table 7).

Table 7.—*Perpetual annual return per acre necessary to provide a present value equal to the purchase price under alternative cost of capital*[1]
(In dollars)

Price per acre	Cost of capital		
	5%	10%	15%
100	5	10	15
200	10	20	30
300	15	30	45
400	20	40	60
500	25	50	75

[1] *Calculated using the formula* $V_o = \frac{r}{i}$

where: V_o = *the initial or present value of a series of payments.*
r = *value recurring annually.*
i = *compound annual rate of interest expressed in decimals.*

Callahan (1966) indicated an average annual return from timber production of $7 per acre per year with a maximum return of $24 per acre per year.

Other sources of revenue from F&A land may include lease or rental for recreational purposes. However, it would most likely be difficult to secure rentals of this magnitude.

SUMMARY

F&A land occupies nearly one-fourth of Illinois. Most of this land is privately owned, but it provides a large number of important public goods and services for which the private owner recieves no revenues. Many public assistance programs are in operation to enhance the management and use of F&A land. These programs must be responsive to changes in public needs, resources, owner goals, and management programs.

One change that has implications for resource management and use is transactions in the land market. An analysis of land transactions in Jackson and Union Counties has indicated that most land transactions include some F&A land. But the amount of F&A land in a sale tends to be small and is often found in association with cropland.

Most of the F&A land sold is covered by a tree canopy and there is not much evidence of land reverting to forest from cropland or pasture. Water resources, including streams and ponds, were located on more than one-fourth of the sales and buildings were located on nearly half of the sales. Roads were found on three-fourths of the tracts. Ten percent of the sales had at least one common boundary with National Forest land.

The price per acre of strictly F&A land varied greatly but averaged $351 in Jackson County and $216 in Union County. These prices exceed what could be justified by past experience with the returns from timber production.

Land changes owners in Jackson and Union Counties at an average annual rate in excess of 3 percent. This tends to create some uncertainty concerning future management and use of these holdings. However, the number of sales and amount of land exchanged shows no significant year to year trends, suggesting that there is no acceleration in the fragmentation of resorce ownership.

Nearly three quarters of the land was purchased by residents of the county where the land was located, and another 10 percent were residents of adjacent counties.

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OXFORD: 652.2:911(773). KEY WORDS: Farm, woodlands, land values, land turnover, land markets, woodland management.

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